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Assessing the viability of compressed natural gas as a transportation fuel for light-duty vehicles in the United States

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Assessing the viability of compressed natural gas as a transportation fuel for light-duty vehicles in the United States

by

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Dedication

I would like to dedicate my thesis to my husband, Cory, who patiently supported me through this process. Thank you, Cory.

Acknowledgements

There are several individuals and organizations I would like to thank for their support. First, I would like to thank my advisor, Dr. Michael E. Webber, for his support and counsel. Not only was Dr. Webber a great teacher in the classroom, but he was also a great role model and mentor. I was honored to be a part of the Webber Energy Group and am thankful to have been able to participate.

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Abstract

Assessing the viability of compressed natural gas as a transportation fuel for light-duty vehicles in the United States

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The University of Texas at Austin, 2011

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Recent optimistic revisions to projections for recoverable natural gas resources in the United States have generated renewed interest in the possibility of greater utilization of natural gas as a transportation fuel. Against a backdrop of significant policy challenges for the United States, including air quality concerns in urban areas, slow economic growth and high unemployment, and a rising unease with regard to an increasing dependence on foreign oil; natural gas offers the nation's transportation sector an opportunity to reduce mobile emissions, lower fuel costs, create jobs and reduce dependence on imported oil.

While the current focus for expanded use of natural gas in the transportation sector emphasizes heavy duty and fleet vehicles, there may also be potential for increased use for passenger vehicles. Inconvenience, with regard to refueling, and high incremental vehicle costs, however, are seen as major obstacles to greater adaptation.

This analysis examines the benefits and drawbacks of natural gas vehicles from the passenger vehicle perspective and includes data from a cross-country road trip. The report includes a review of market trends and possible development scenarios and concludes with recommendations to minimize the potential challenges of greater adaptation of natural gas vehicles in the passenger vehicle market.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

BCFD	Billion Cubic Feet per Day
BTU	British Thermal Units
CBM	Coal Bed Methane
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
DOE	Department of Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPAct	Energy Policy Act of 2005
GDP	Gross Domestic Product
GGE	Gallon of Gasoline Equivalent
GHG	Greenhouse Gas
GM	General Motors
GTL	Gas-to-Liquids
KWH	Kilowatt Hour
LFG	Land Fill Gas
LNG	Liquefied Natural Gas
MCF	Thousand Cubic Feet
MMBD	Million Barrels a Day
MMBTU	Million British Thermal Units
MPG	Miles Per Gallon

NAT GAS Act	New Alternative Transportation to Give Americans Solutions Act
NGV	Natural Gas Vehicle
NOx	Nitrous Oxide
OEM	Original Equipment Manufacturer
PGC	Potential Gas Committee
RFS	Renewable Fuel Standard
SO_2	Sulfur Dioxide
SUV	Sports Utility Vehicle
TCEQ	Texas Commission on Environmental Quality
TCF	Trillion Cubic Feet
TERP	Texas Emission Reduction Plan
TX	Texas
US	United States
VMT	Vehicle Miles Travelled

Chapter 1: Introduction

Historically, natural gas has been primarily utilized for power generation, as an industrial feedstock, and in residential applications for home heating and cooking. But recent increases to estimates of recoverable natural gas reserves in the United States (U.S.) combined with an emphasis on lower emissions make the possibility of utilizing this resource as a transportation fuel a pressing policy question. The news of additional natural gas supplies comes at a time when the U.S. faces various challenges, including a delicate national security situation as a result of the nation's dependence on foreign energy sources, an increasing awareness of the environmental implications of energy choices, and a need to preserve and add domestic jobs to an economy that is increasingly exporting jobs. Greater utilization of natural gas as a transportation fuel might help address some of these challenges, and is the topic of this research.

As a domestic resource, replacing transportation fuel made from oil with natural gas could reduce dependence on energy imports. Further, because natural gas burns relatively cleanly, its use could reduce emissions relative to gasoline, for example yielding lower carbon dioxide (CO_2), lower nitrous oxide (NO_X), and lower carbon monoxide (CO) emissions. Natural gas in the form of compressed natural gas (CNG) is also significantly cheaper (at today's prices), averaging approximately 30 percent less than gasoline, meaning significant fuel cost savings over the operational life of a natural gas vehicle (NGV) can be achieved.

Yet, even in light of these benefits, challenges remain, including high incremental vehicle cost and a lack of sufficient refueling infrastructure. While heavy-duty and fleet vehicles make attractive targets for early adoption given the high-mileage and high-fuel usage of these vehicles, there are also a limited number of NGVs for passenger use available for purchase.

There could be potential for growth in the passenger vehicle market, however. Passenger NGVs are popular in other areas of the world, and while there are limited original equipment manufacturer (OEM) passenger vehicle options, there are several conversion kit options available in the U.S. There is also the possibility of home refueling for passenger NGVs. These factors make the passenger NGV option worthy of examination for the U.S.

The direct personal experience that was gathered during an experimental NGV road trip, along with the well-documented data on natural gas vehicles, imply that NGVs can offer personal and societal benefits from fuel cost savings, reduced emissions and energy security benefits. However, the high upfront costs for society (through expensive infrastructure) and for individuals (who pay the premium for NGVs) remain critical hurdles that make it difficult for passenger NGV owners to recover their financial investment over an acceptable payback period.

While modest government programs to incentivize the American NGV market exist at the federal and state level, more could be done to encourage NGV use. For example, Congress is currently considering legislation that would offer a federal income tax credit for NGV vehicle purchases and refueling infrastructure development, legislation that some predict could help jump-start the market and encourage greater use of NGVs on a wider scale.

A review of costs associated with purchasing and operating passenger NGVs reveals, in the short-term, payback periods will remain prohibitively long and outside an acceptable range without significant incentives. Early adopters will be motivated by more than just economics to justify the move to natural gas. Nonetheless, absent government incentives, there are additional longer-term scenarios whereby the option might become more economically attractive for passenger vehicle consumers.

An assessment of the benefits and challenges of passenger NGV use, the results of the experimental road trip, a discussion of market trends, and a review of possible scenarios whereby passenger NGVs could overcome certain challenges are included in this analysis. Following an introduction in Chapter One, Chapter Two explores the current U.S. transportation sector and describes the current passenger vehicle fleet profile as well as current fuel use. Chapter Three examines the domestic natural gas resource base and includes a review of both conventional and unconventional resources. Chapter Four continues by describing the natural gas vehicle option and detailing the benefits and challenges of using natural gas as a transportation fuel. In Chapter Five, the results from the experimental NGV road trip are reviewed and lessons learned from the road are shared. Chapter Six examines current incentives to encourage NGVs and considers pending legislative NGV proposals. Finally, Chapter Seven draws the research to a close with final conclusions.

Chapter 2: Transportation Background

2.1 U.S. Transportation Sector: Driving Domestic Fuel Demand

2.1.1 Passenger Fleet Profile

The transporting of goods and people in the United States is a significant driver in the country's overall energy consumption. The U.S. on-road vehicle fleet includes light, medium and heavy-duty vehicles. According to the U.S. Department of Transportation, in 2008, there were a total of 256 million vehicles on the road, of which 238 million were light duty. Light duty vehicles include light duty trucks and cars, the vehicles most commonly used as passenger vehicles (Research and Innovation Technology Administration, 2010).

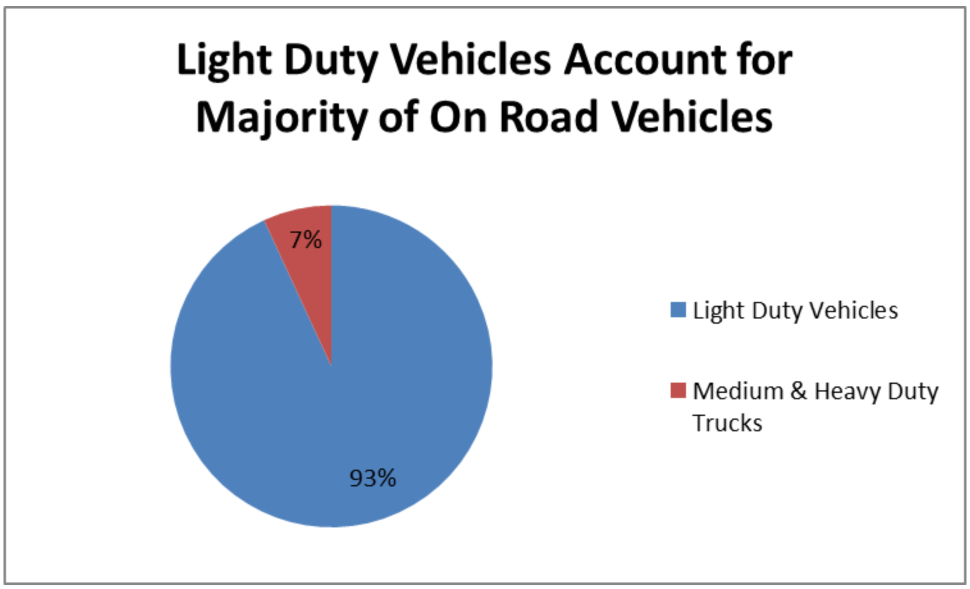


Figure 1: Passenger Vehicles Account for Majority of On Road Vehicles (Research and Innovation Technology Administration, 2010)

In 2008, the passenger vehicle total included 58 percent cars and 42 percent light duty trucks. The below chart shows that the percentage of the passenger fleet attributed to light duty trucks has been increasing over time. This change is due, in part, because of the introduction and popularity of the sports utility vehicle (SUV) (Gladwell, 2004).

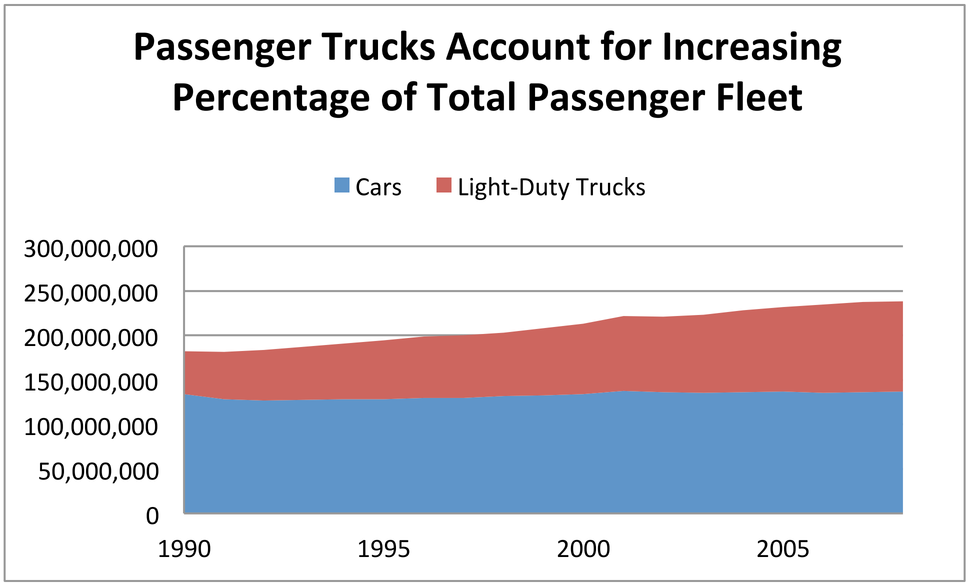


Figure 2: Passenger Trucks as a Percentage of Total Passenger Fleet (Research and Innovation Technology Administration, 2010)

2.1.2 Transportation & Fuel Use

Energy consumption for transportation needs accounted for nearly 27 percent of all energy consumed in 2009. The below EIA diagram shows that approximately 94 percent of this energy demand was met by petroleum, 3 percent by natural gas (for mostly pipeline transportation), and 3 percent by biomass, electricity, or other fuels. In other words, moving people and goods around the nation takes up over a quarter of all energy consumed, and nearly all of that comes from oil.

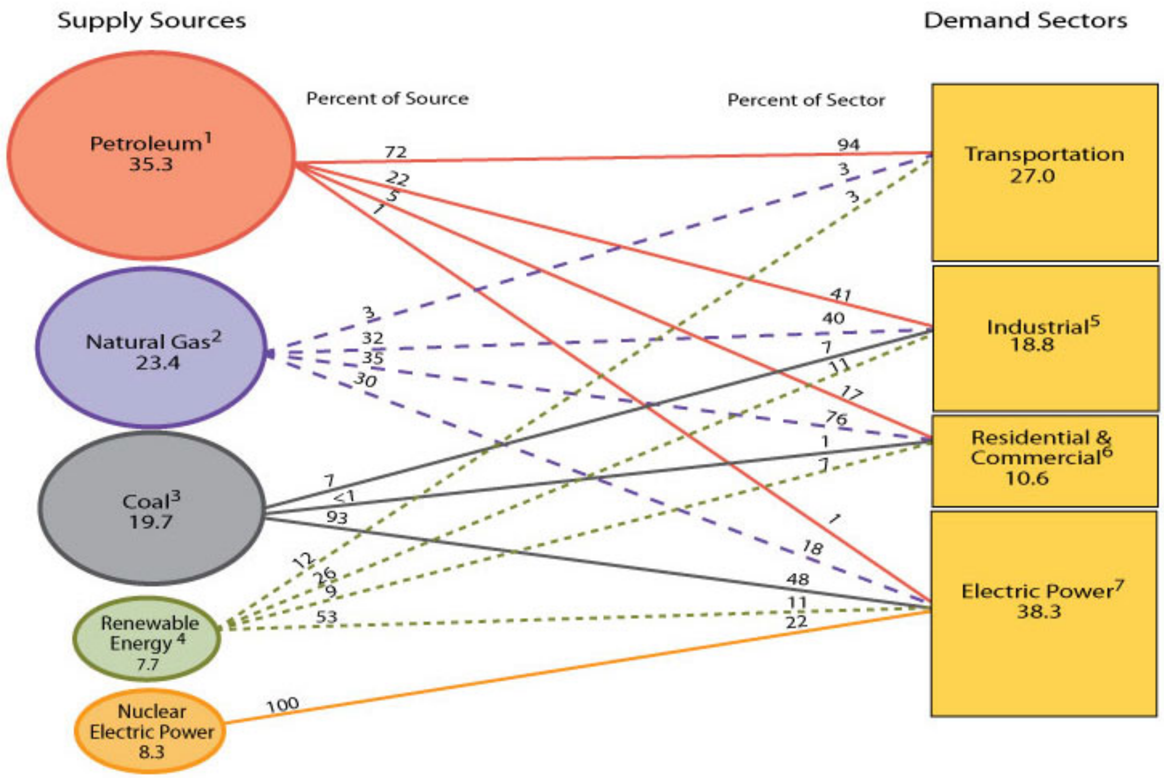


Figure 3: U.S. Primary Energy Flow by Source and Sector, 2009 (Quadrillion BTU) (U.S. Energy Information Administration, 2010)

U.S. demand for all types of transportation fuel is driven by both highway and non-highway transportation, including light duty vehicles, buses, heavy duty vehicles, air, rail and pipeline transport, as detailed in the below table. In 2008, light duty vehicles represented a significant component of transportation energy demand accounting for 61.3 percent of total demand (Davis, Diegel, & Boundy, 2010).

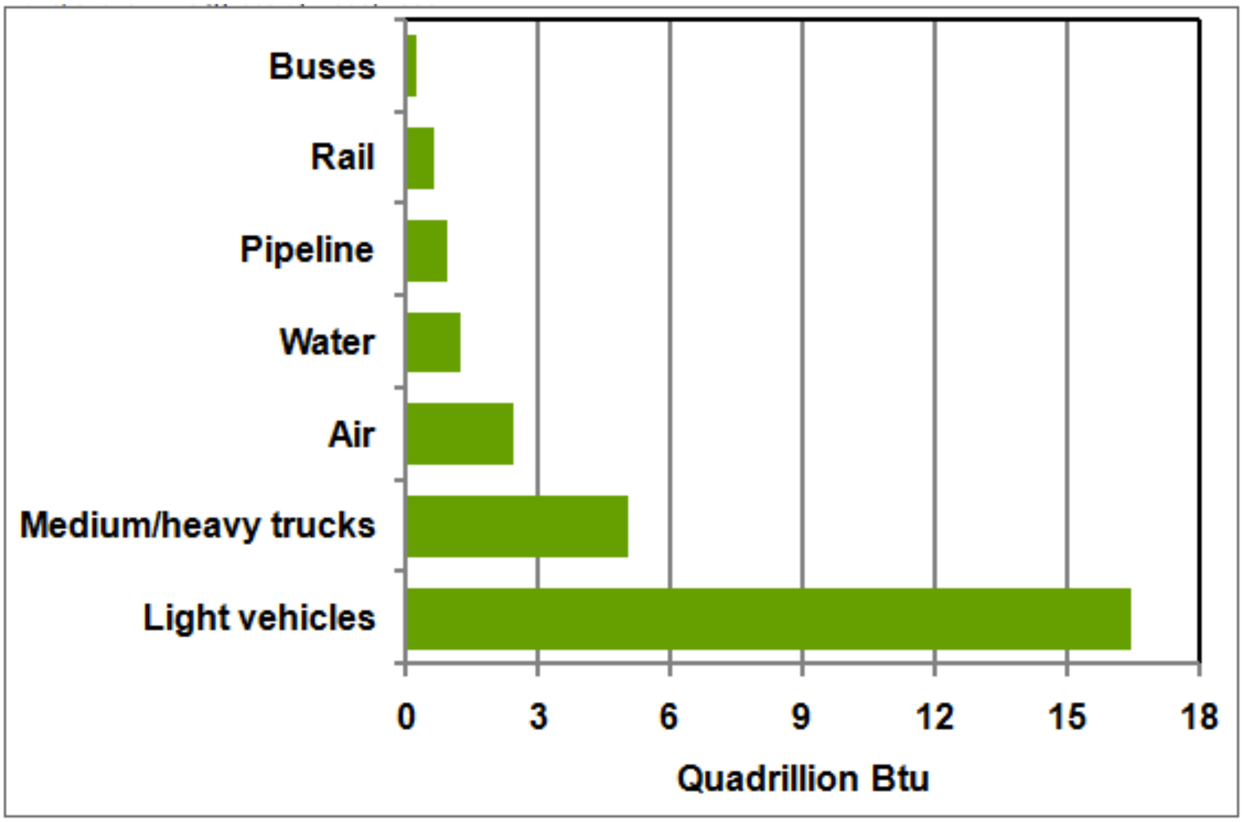


Figure 4: Transportation Energy Use By Mode, 2007-2008 (Davis, Diegel, & Boundy, 2010)

In fact, in 2008, total fuel use for the light duty sector represented 97 percent of total gasoline demand in the transportation sector and 8 percent of diesel demand (U.S. Department of Energy). The below chart illustrates the fuel demands of various aspects of the transportation market.

	Gasoline	Diesel fuel	Liquified petroleum gas	Jet fuel	Residual fuel oil	Natural gas	Electricity	Total
HIGHWAY	**16,513.8**	**5,060.8**	**61.5**			**20.4**	**0.6**	**21,657.1**
Light vehicles	**16,001.9**	**389.1**	**44.7**			**0.0**	**0.0**	**16,435.7**
Cars	8,781.8	49.6						8,831.4
Light trucks[b]	7,188.0	339.5	44.7					7,572.2
Motorcycles	32.0							32.0
Buses	**7.2**	**171.5**	**0.0**			**20.4**	**0.6**	**199.8**
Transit	0.5	73.7	0.0			20.4	0.6	95.3
Intercity		30.3						30.3
School	6.8	67.5						74.3
Medium/heavy trucks	**504.7**	**4,500.2**	**16.8**					**5,021.6**
NONHIGHWAY	**237.7**	**794.3**	**0.0**	**2,355.6**	**795.8**	**668.0**	**314.0**	**5,165.4**
Air	**37.7**	**0.0**	**0.0**	**2,355.6**	**0.0**	**0.0**	**0.0**	**2,393.3**
General aviation	37.7			228.0				265.7
Domestic air carriers				1,710.0				1,710.0
International air carriers[c]				417.6				417.6
Water	**200.0**	**231.5**			**795.8**			**1,227.2**
Freight		185.8			795.8			981.6
Recreational	200.0	45.7						245.7
Pipeline	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**668.0**	**242.5**	**910.5**
Rail	**0.0**	**562.9**	**0.0**	**0.0**	**0.0**	**0.0**	**71.5**	**634.4**
Freight (Class I)		542.5						542.5
Passenger		20.4					71.5	91.9
Transit		0.0					47.8	47.8
Commuter		11.6					17.8	29.3
Intercity		8.8					6.0	14.8
TOTAL HWY & NONHWY	**16,751.5**	**5,855.2**	**61.5**	**2,355.6**	**795.8**	**688.5**	**314.6**	**26,822.6**

Table 1: Domestic Consumption by Mode and Fuel Type, 2008 (trillion BTU) (Davis, Diegel, & Boundy, 2010)

The below figure suggests that demand for transportation fuels will continue to rise through 2035 with light duty vehicles continuing to account for more than half of the demand.

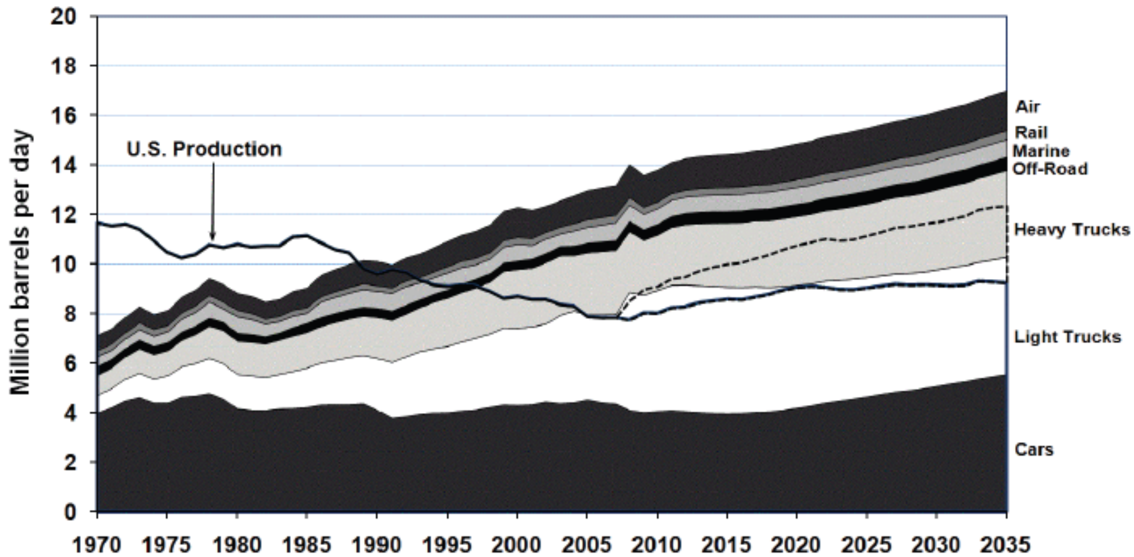


Figure 5: Domestic Consumption of Transportation Energy by Mode and Fuel Type, 2008 (trillion BTU) (Davis, Diegel, & Boundy, 2010)

2.1.3 Sourcing the Fuel

Petroleum products, such as gasoline and diesel, are manufactured by refining crude oil. The U.S., however, does not produce enough oil to meet petroleum product demand domestically. In fact, the U.S. only produced 5.4 million barrels of oil per day (MMBD) in 2009 and imported approximately 9 MMBD of oil from foreign countries (U.S. Energy Infromation Administration, 2011).

The chart below indicates that U.S. dependence on foreign crude oil has been a growing trend over the last 60 years. A noticeable drop in consumption and, therefore, net imports occurred in 2009 with the reduced demand of the economic slowdown.

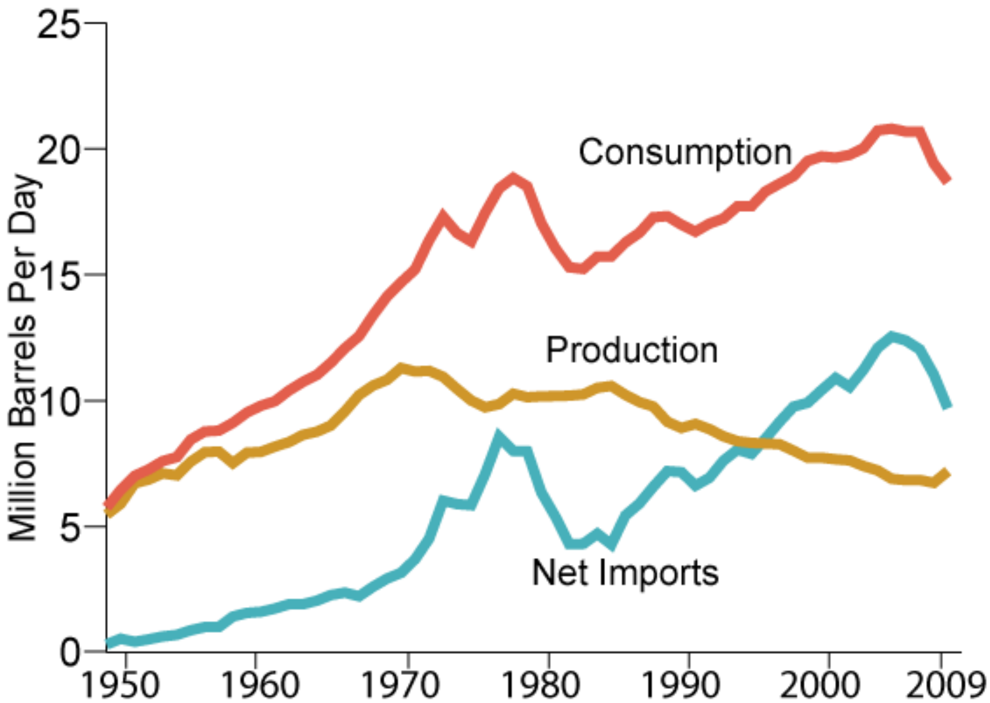


Figure 6: Consumption, Production, and Import Trends, 1949-2009 (U.S. Energy Information Administration, 2011)

The U.S. imports oil from a variety of foreign sources, over half of which are countries in the western hemisphere. The top five suppliers include Canada (23.3 percent), Venezuela (10.7 percent), Saudi Arabia (10.4 percent), Mexico (9.2 percent) and Nigeria (8.3 percent) (U.S. Energy Information Administration, 2011). The below pie chart illustrates the percentage of imports by region.

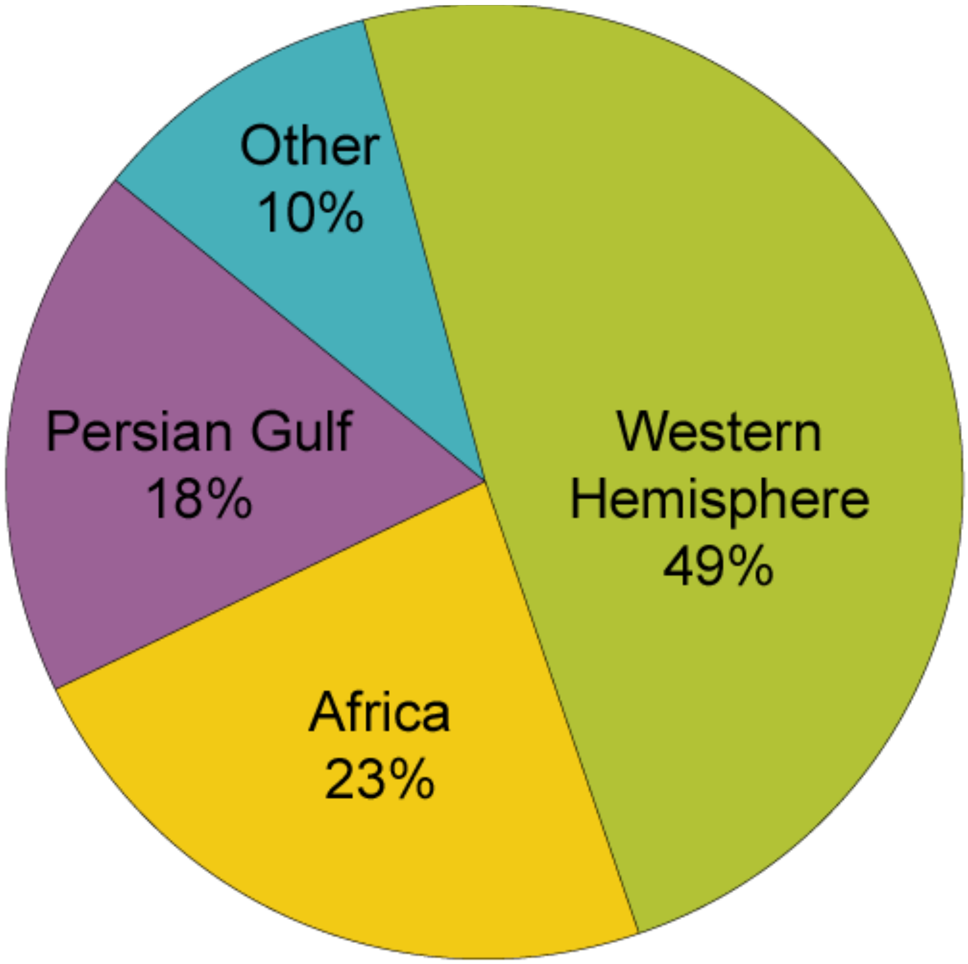


Figure 7: U.S. Net Petroleum Imports by Region, 2010 (U.S. Energy Information Administration, 2011)

Military experts contend that U.S. dependence on foreign oil poses a significant threat by endangering both economic and national security. The Center for Naval Analysis's Military Advisory Board recently commented that, "Our dependence on foreign oil reduces our international leverage, places our troops in dangerous global regions, funds nations and individuals who wish us harm, and weakens our economy; our dependency and inefficient use of oil also puts our troops at risk" (Wellkamp & Weiss, 2010).

Secure America's Future Energy (SAFE) recently reported that the combined economic costs of U.S. oil dependence reached $750 billion in 2008. SAFE further concludes that our dependence has cost the country beyond just the dollars spent on barrels of foreign crude; personnel and assets of the U.S. military are strategically positioned all over the world to help secure crude supplying nations. The below chart shows an estimated cost of U.S imports, taking into account wealth transfer, dislocation losses and loss of potential GDP. The total figure for 2008 (just before the economic slowdown) was nearly $500 billion dollars, with wealth transfer accounting for over half of the cost. In addition to costs, U.S. foreign policy can often be hamstrung by our dependence on foreign oil as we try to negotiate with foreign nations on extemporaneous policy issues, such as uranium enrichment in Iran or the brutal dictatorships in Africa (Energy Security Leadership Council, 2008).

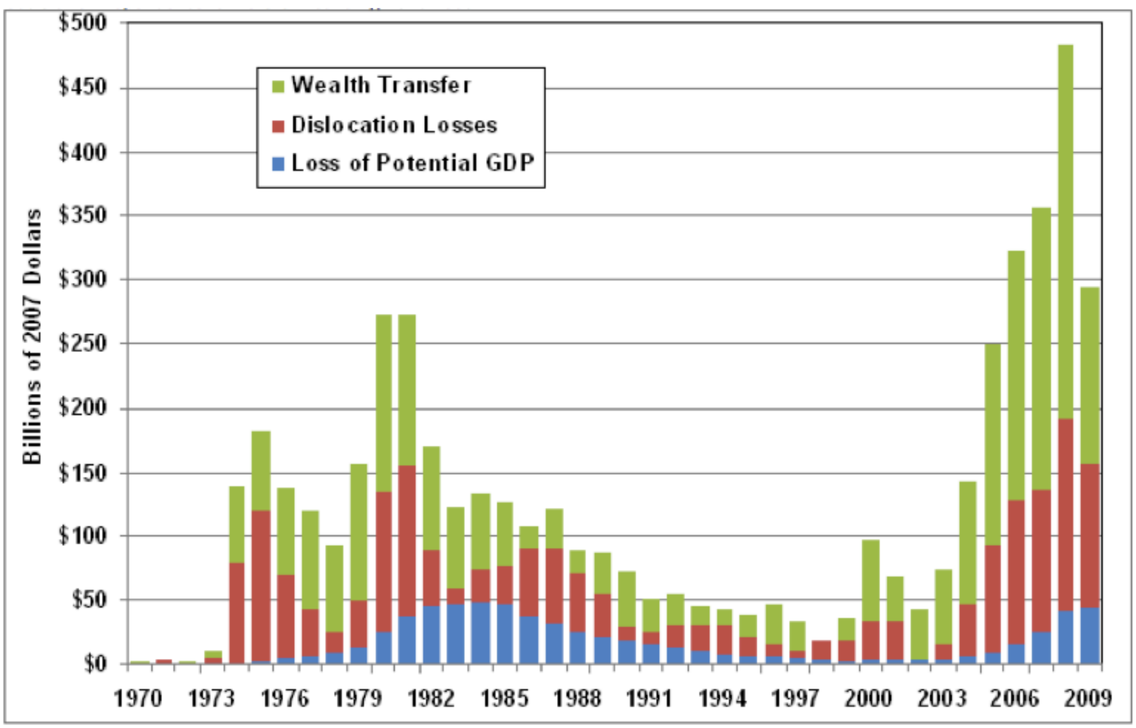


Figure 8: Cost of Oil Dependence to U.S. Economy, 1970-2009 (Vehicle Technologies Program, 2010)

2.1.4 Current Strategies to Reduce Oil Dependence

The dependence on crude oil for transportation and the growing nature of that need being met increasingly by foreign sources has long been a challenge of U.S. energy policy. Dating back to the 1970s, strategies have been discussed and implemented to try to wean total demand for oil, or at least replace part of the demand with fuel alternatives. At the federal level, there have been various efforts to reduce oil use in the transportation sector, including a push for increased fuel efficiency, a search for an alternative liquid fuel and the mandating of ethanol blending, as well as an effort to move away from liquid fuels altogether and promote electric vehicles.

Beginning in the 1970s, efforts began to encourage automakers to improve the overall efficiency of the vehicles, allowing travellers to do more with less (National Research Council of the National Academies, 2010). In 1975, the federal government put mileage standards in place, which doubled passenger fuel efficiency over the next 10 years, bringing the fleet average to 27.5 miles per gallon (MPG). New standards were passed nearly 30 years later, which will push passenger vehicle efficiency to 36 MPG and light-duty trucks to 28 MPG by the year 2016 (IHS CERA, 2010). In July 2011, President Obama announced even stricter standards for 2025, which would require cars and light trucks to achieve a fleet wide average of 54.5 MPG by 2025 (Banerjee, 2011).

2.1.4.1 Reducing Demand

Even in the absence of stricter standards from the federal government, vehicle efficiency has been improving simply through technological advancement over the years. For example, vehicle drive-train efficiency has been improving at a rate of about 1 percent per year (National Research Council of the National Academies, 2010).

Interestingly, however, in light of improved efficiency, Americans are choosing larger and heavier vehicles, negating potential fuel savings that could have been realized. So, in spite of technological improvements in the efficiency of vehicle components, the fuel demand has continued to rise, and the U.S. light-duty vehicle fleet now has an average new-vehicle fuel efficiency of about 25 mpg (National Research Council of the National Academies, 2010).

2.1.4.2 Shifting Demand

The second federal strategy aimed at reducing petroleum dependence in the transportation sector is the support for and mandating use of biofuels, principally corn-based ethanol. The 2005 Energy Policy Act (EPAct) created a Renewable Fuel Standard (RFS), which mandated the use of renewable fuels in the United States. The original program required 7.5 billion gallons of renewable fuel to be blended into gasoline by 2012 (U.S. Environmental Protection Agency, 2010).

In 2007, the program was expanded in the Energy Independence and Security Act (EISA) of 2007, increasing production requirements to 36 billion gallons of biofuels by 2022 and providing about 20 percent of the fuel mix (U.S. Environmental Protection Agency, 2010).

IHS CERA points out that the new RFS requirements will "not only reduce oil usage in transportation, it will also slightly increase natural gas demand because natural gas is used to make corn-based ethanol." The 2007 law mandated that only 15 billion gallons of the total requirement of 36 billion could come from corn-based ethanol, with the remainder needing to come from other biofuel sources such as cellulosic (IHS CERA, 2010).

The third federal strategy aimed at curbing U.S. dependence on oil for transportation is an effort to move away from liquid fuels altogether and, instead, move to power vehicles through electricity. The crux of the federal government's role in this effort involves RD&D into the battery component of the electric car, the most challenging piece to reaching a competitive price For example, in the American Recovery and Reinvestment Act of 2009, nearly $2 billion in stimulus funds were set aside for advanced battery manufacturing and other electric vehicle (EV) parts (IHS CERA, 2010).

Vehicles powered by alternative fuels (AFV), including biofuels and electricity efforts described above, have gotten off to a sluggish start. According to the EIA, as of 2009, the U.S. alternative fueled vehicle (AFV) inventory estimate totaled 826,318 in 2009, of which approximately 14 percent or 114,270 were CNG vehicles (U.S. Energy Information Administration, 2011).

Alternatives to Traditional Transportation Fuels, 2009

Release Date: April 2011

Next Release Date: April 2012

Table V1. Estimated Number of Alternative Fueled Vehicles in Use in the United States, by Fuel Type, 2005 - 2009

Fuel Type	2005	2006	2007	2008	2009
Compressed Natural Gas (CNG)	117,699	116,131	114,391	113,973	114,270
Electricity (EVC)[1]	51,398	53,526	55,730	56,901	57,185
Ethanol, 85 percent (E85)[2,3]	246,363	297,099	364,384	450,327	504,297
Hydrogen (HYD)	119	159	223	313	357
Liquefied Natural Gas (LNG)	2,748	2,798	2,781	3,101	3,176
Liquefied Petroleum Gas (LPG)	173,795	164,846	158,254	151,049	147,030
Other Fuels (OTH)[4]	3	3	3	3	3
Total	**592,125**	**634,562**	**695,766**	**775,667**	**826,318**

[1]Excludes gasoline-electric and diesel-electric hybrids because the input fuel is gasoline or diesel rather than an alternative transportation fuel. DOE, which has EPACT92 implementation authority, ruled that gasoline-electric and diesel-electric hybrids are not "alternative fuel vehicles."

[2]In 1997, some vehicle manufacturers began including E85 fueling capability in certain model lines of vehicles. For 2009, the EIA estimates that the number of E85 vehicles that are capable of operating on E85, gasoline, or both, is about 10 million. Many of these alternative fueled vehicles (AFVs) are sold and used as traditional gasoline-powered vehicles. In this table, AFVs in use include only those E85 vehicles believed to be used as AFVs. These are primarily fleet-operated vehicles.

[3]The remaining portion of 85-percent ethanol is gasoline.

[4]May include P-Series fuel or any other fuel designated by the Secretary of Energy as an alternative fuel in accordance with the Energy Policy Act of 1992.

Notes: Vehicles in Use do not include concept and demonstration vehicles that are not ready for delivery to end users.

Vehicles in Use represent accumulated acquisitions, less retirements, as of the end of each calendar year.

The estimated number of neat methanol (M100), 85-percent methanol (M85), and 95-percent ethanol (E95) vehicles in use is zero for all years included in this table. Therefore, those fuels are not shown.

Source: U.S. Energy Information Administration, Office of Energy Consumption and Efficiency Statistics and the DOE/GSA Federal Automotive Statistical Tool (FAST).

Table 2: Alternative Fueled Vehicles (AFV) in Use in U.S. by Fuel Type, 2005-2009 (U.S. Energy Information Administration, 2011)

The slow growth and relatively small fraction of the total vehicle fleet may not be enough to make a significant impact on fuel demand. The below chart suggests that even with the above-mentioned general strategies (increased efficiency, increased biofuel use and adoption of electric vehicle technologies), by 2030 the transportation sector in the United States remains heavily dependent on oil based fuels (IHS CERA, 2010).

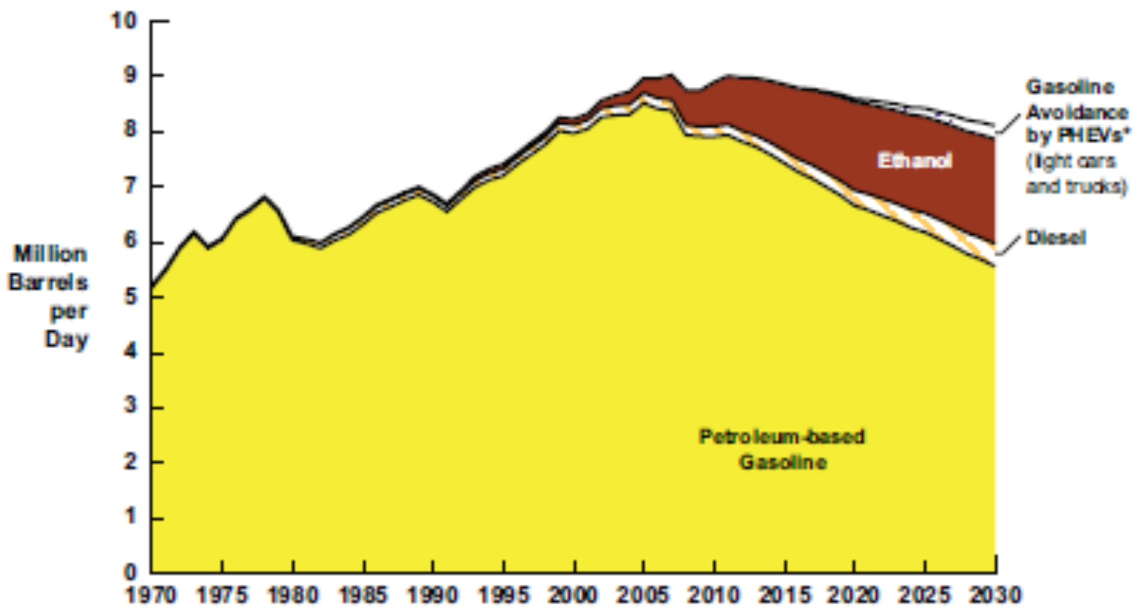


Figure 9: U.S. LD Vehicle Fuel Demand in Demand Reduction Scenario (IHS CERA, 2010)

2.2 Conclusion

Energy needed to meet transportation demand accounts for nearly a quarter of total U.S. energy demand and consumes nearly three quarters of total petroleum demand. The light duty market accounts for approximately two thirds of the transportation sector's petroleum needs underscoring its significant role in total U.S. petroleum demand. In order to meet total petroleum needs, the U.S. must supplement domestic production by importing nearly 60 percent of the total oil demand, a dependence experts cite as threatening national security. Efforts have been made to decrease petroleum dependence in the transportation sector by improving vehicle efficiency and by encouraging the switch to alternative –fueled vehicles including electrics.

Chapter 3: Natural Gas Background

As mentioned in the previous section, natural gas as a transportation fuel is considered an alternative to gasoline. Understanding the basics of the fuel and its intrinsic characteristics will assist in determining if it's a suitable alternative fuel.

3.1 Chemical Description

Natural gas is a colorless and odorless combination of combustible hydrocarbon gases. Natural gas is primarily methane, which makes it an inherently less carbon intensive than gasoline due, in part, to its simple chemical make-up of one carbon atom and four hydrogen atoms. In addition, its combustion chemistry generally yields fewer pollutants compared with the combustion of wood, coal or petroleum. These characteristics will be discussed in greater length in the section on environmental impacts of combustion.

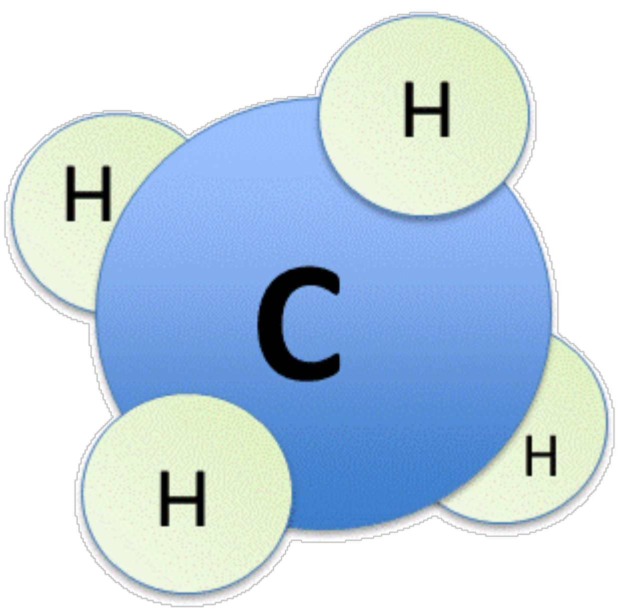


Figure 10: Image of a Molecule of Methane

3.2 U.S. Natural Gas Consumption

Natural gas meets over 23 percent of the U.S.'s total energy needs in residentential, commercial industrial, and electric generation applications (Natural Gas Supply Association, 2010). The below figure details the breakdown among the various use categories.

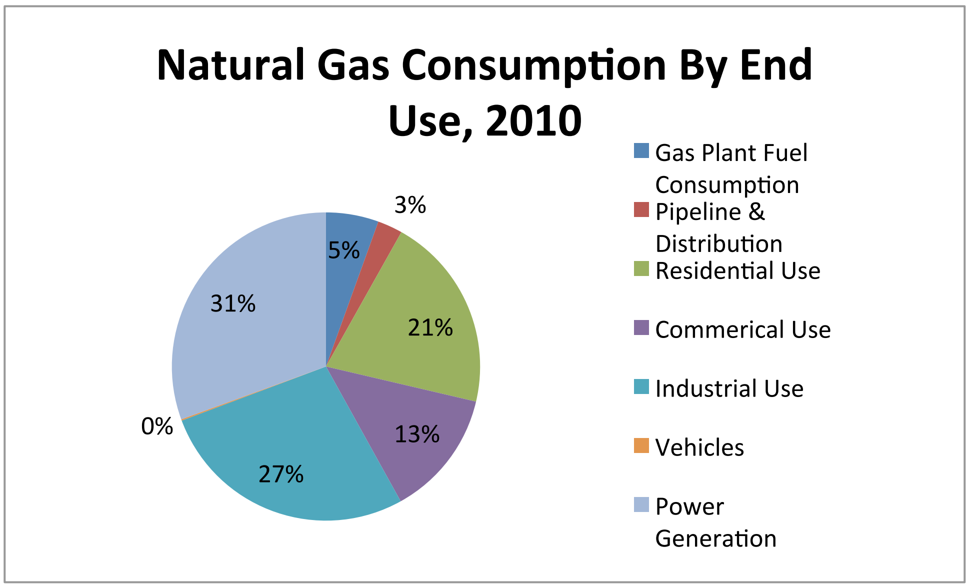


Figure 11: Natural Gas Consumption by End Use, 2010 (U.S. Energy Information Administration, 2011)

Residential (21 percent) uses include home appliances such as water heaters, air conditioners, furnaces, dryers, and stoves/cooktops, and to a lesser extent vehcile refueling appliances. Similarly, commerical (13 percent) uses of natural gas include space and water heating and cooling, and for cooking in restaurants.

Many industrial (27 percent) customers, such as refining, processing, pulp and paper and metals industries, use natural gas as both a power generation source (for lighting or machinery), as a source of process heat, and as a feedstock for products such as plastics and fertilizers.

In 2010, power generation represented the largest section of gas consumption at 31 percent of the total. Because of the clean-burning attributes of the fuel and realtively lower cost of plant construction, natural gas for electric generation has recently (over the last 15 years) enjoyed significant capacity additions. As the graph suggests, EIA anticpates natural gas will continue to play a predominant role in new power generation capcity through 2035 (U.S. Energy Information Administration, 2011).

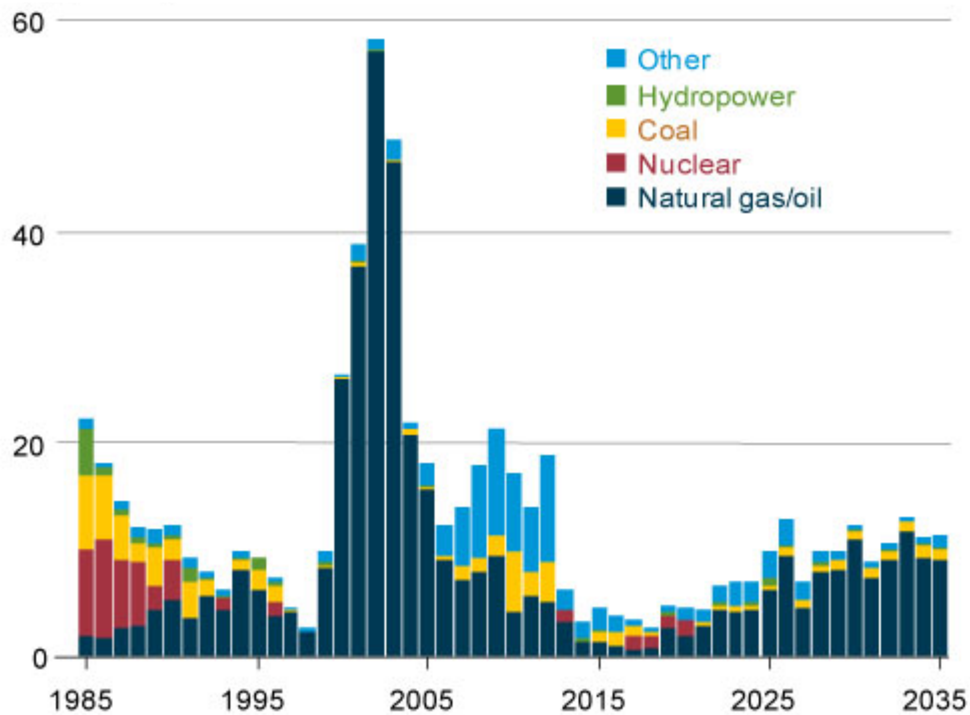


Figure 12: Additions to Electricity Generation Capacity, 1985-2035 (U.S. Energy Information Administration, 2011)

Total gas consumption in 2010 was 24.13 TCF, but the below chart shows the seasonality of gas demand over time. Annual peak demand occurs in the winter when natural gas is being used for heating. The summer month see an additional bump (although not as significant as winter) as demands for power generation increase for electic air conditioner cooling. Shoulder months or those seen as the valleys below represent spring and fall when weather is more temperate.

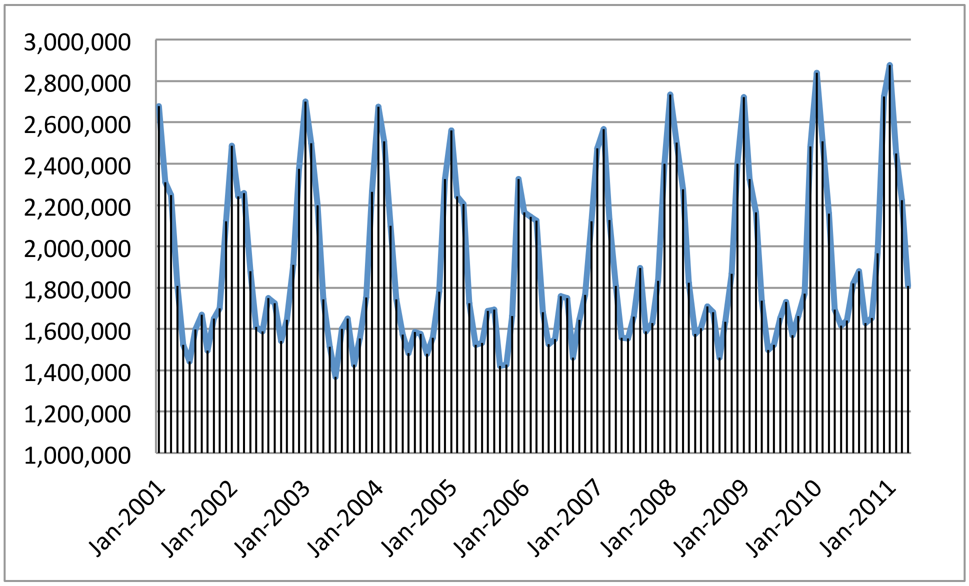


Figure 13: Natural Gas Consumption by End Use, 2010 (U.S. Energy Information Administration, 2011)

3.3 U.S. Natural Gas Resource Base

Natural gas is either thermogenic, created by buried organic material, or biogenic, created by methanogenic organisms in shallow sediments closer to or at the surface. The majority of natural gas resources globally are created by thermogenic processes. This occurs in underground reserves where millions of years ago organic materials, specifically plant and animal material, was buried under layers of rock and decayed over time. Pressure and heat altered the organic material, and transformed it into natural gas. This process is similar for other fossil fuels such as oil and coal.

Thermogenic natural gas has been domestically produced in the United States since the early 1800s. In 1821, after noticing bubbles rising from a creek in Freedonia, New York, William Hart dug the first well specifically intended to capture natural gas from below ground and bring it to the surface (Natural Gas Supply Association , 2010).

Since Hart's efforts, traditional underground reservoirs have been successfully produced on and offshore in the US. In addition to traditional sources, recent developments have also led to the production of gas from unconventional resources such as shale formations, coal bed methane and even biogenic sources, such as landfill gas. In addition to these sources, very promising resource estimates suggest there could be vast amounts of natural gas offshore in the form of methane hydrates.

3.3.1 Traditional or Conventional Sources

Traditional or conventional natural gas reservoirs provide the majority of current domestic production and typically refer to underground sandstone formations. There are nearly 425,000 wells across the country producing natural gas, the majority of which tap into conventional sources including resource-rich deposits offshore. The EIA map below shows major conventional fields in the lower 48 states (ConocoPhillips, 2011).

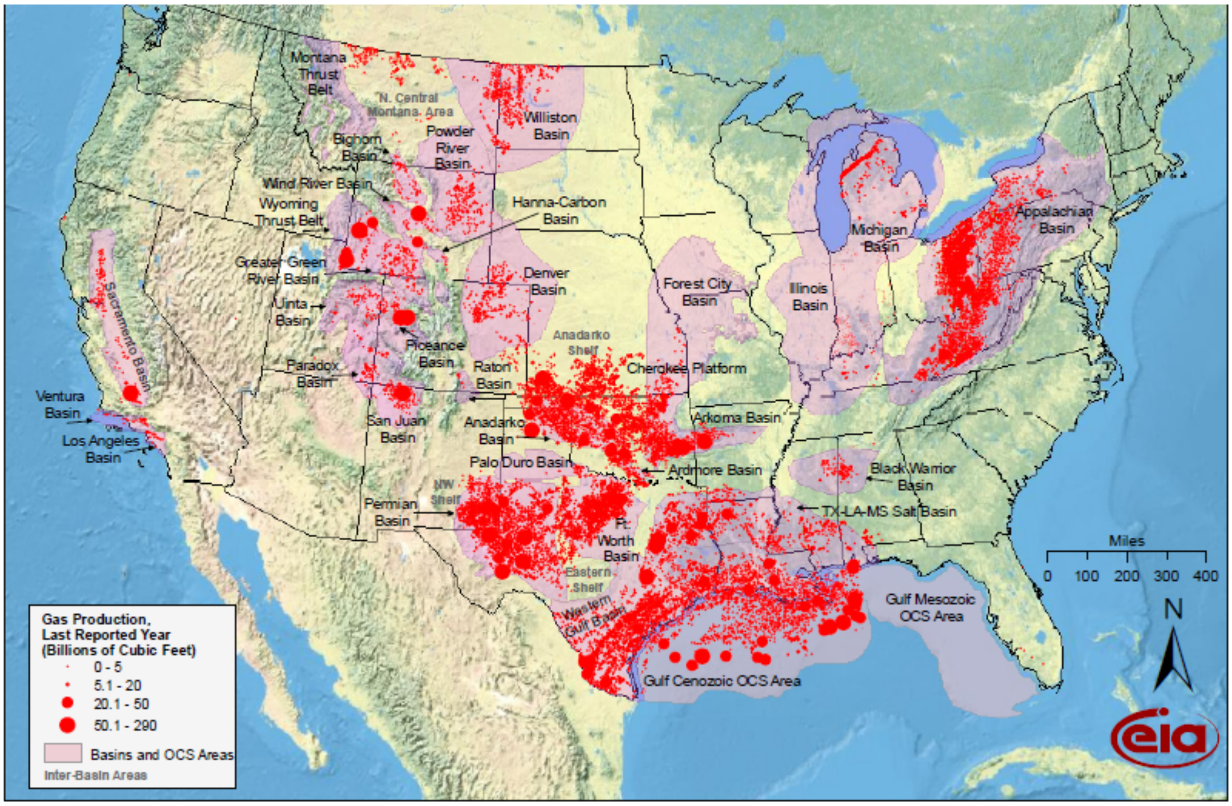


Figure 14: Gas Production in Conventional Fields, Lower 48 States (U.S. Energy Information Administration, 2009)

3.3.2 Unconventional Sources

Unconventional natural gas resources typically refer to coalbed methane (CBM) and shale gas. The application of new technologies has unlocked previously uneconomic natural gas resources, allowing geologists to convert them to proved reserves. EIA began reporting reserves data separately for CBM in 1990 and for shale gas in 2008.

CBM is natural gas trapped in an underground coal seam. Domestically, CBM is found in Alabama, Colorado, Illinois, Kansas, Kentucky, Montana, New Mexico, Ohio, Oklahoma, Texas, Utah, West Virginia and Wyoming. The below EIA map shows that active CBM fields overlap major coal basins.

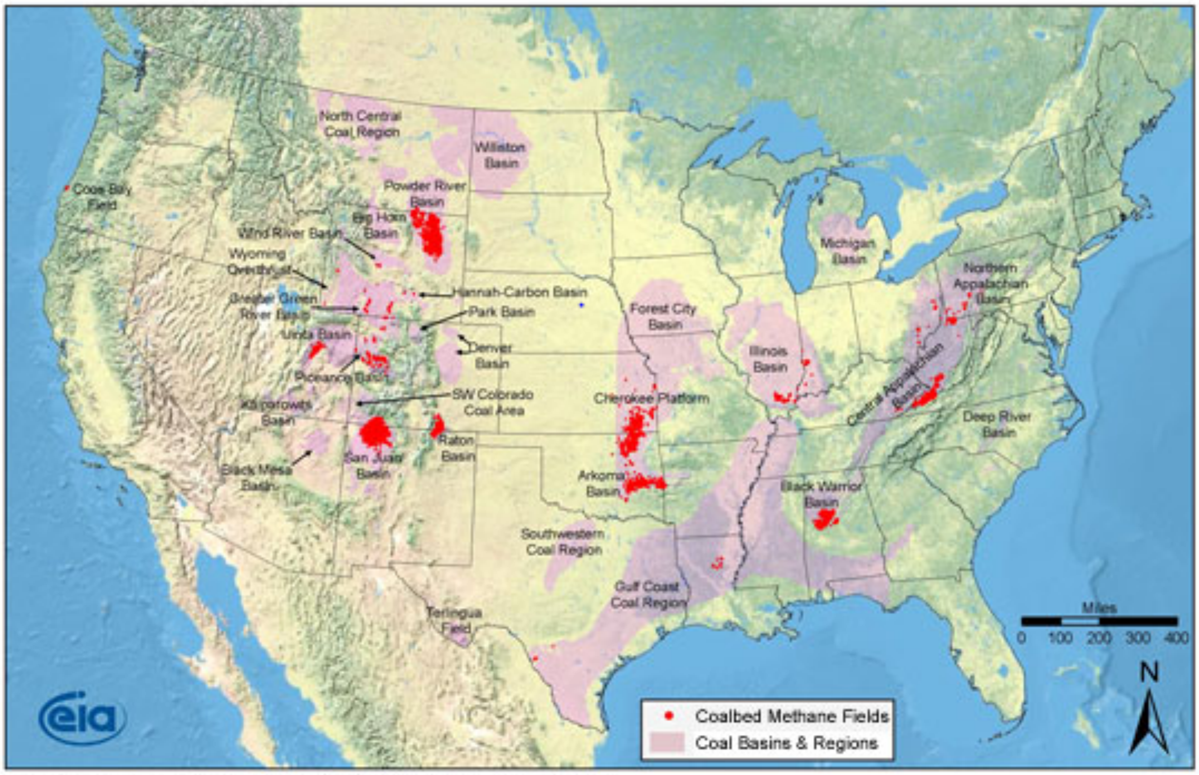


Figure 15: Coalbed Methane Fields, Lower 48 (U.S. Energy Information Administration, 2009)

In addition to traditional natural gas reserves, recent technological advances in horizontal drilling and stimulation techniques, such as hydraulic fracturing, have led to the development of vast unconventional natural gas resources locked in shale formations across the country. These shale resources had been historically considered too expensive to produce but technology and a period of higher prices helped unlock these additional resources, adding significantly to total U.S. natural gas reserves. The figure below contains a map of shale plays in the United States. According to EIA, in 2010 shale gas accounted for nearly 23 percent of U.S. natural gas supply, up from just two percent in

2000. EIA further estimates that shale gas will account for 47 percent of U.S. gas supply by 2035.

Figure 16: Shale Plays, Lower 48 (U.S. Energy Information Administration, 2011)

3.3.3 Other Potential Sources

3.3.3.1 Methane Hydrates

While less is known about the potential resource base of methane hydrates, it is worth mentioning the early estimates of this vast offshore resource. Methane hydrates are ice-like solids whereby water molecules trap gas molecules in a lattice-like structure. According to the U.S. Geological Survey, estimates of the global resource for methane hydrates range from 100,000 to 300,000,000 trillion cubic feet (TCF). Considering these resource numbers in the context of total current U.S. resource estimates of nearly 2,000

TCF, underscores the potential size of methane hydrates resources (U.S. Geological Survey, 2001).

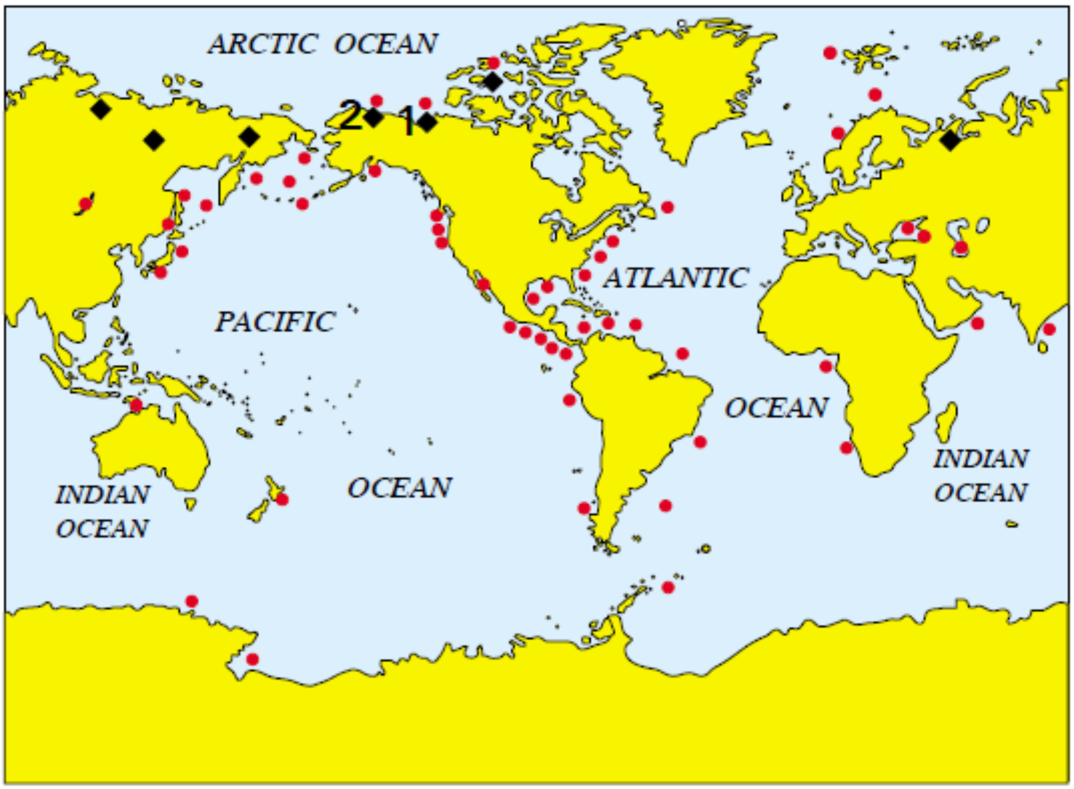


Figure 17: Known and Inferred Natural Gas Hydrate Occurrences (U.S. Geological Survey, 2001)

3.3.3.2 Biogas

In addition to thermogenic natural gas formed over millions of years underground, methane can also be produced at the surface as a byproduct of anaerobic digestion; one example being landfill gas (LFG), or the methane gas given off as organic materials in a landfill decay (Alternative Fuels and Advanced Vehicle Data Center, 2011).

Certain microorganisms produce methane as a byproduct of metabolism, also known as methogenic organisms. Methogenic organisms are found in landfills (generating landfill gas), wetlands (generating marsh gas), and even in the digestive system of certain animals, including humans and cows, and generating belches and flatulence (McGraw-Hill Concise Encyclopedia of Environmental Science, 2008).

Landfill facilities can capture the gas as it is created. The resulting gas is a combination of methane, carbon dioxide, nitrogen and water vapor. The gas can be processed to isolate the methane, however, producing pipeline quality natural gas (U.S. Energy Information Administration, 2008).

In addition to production at landfills, biogas can also be captured from sewage waste treatment plants and animal feedlots. Historically, the gas formed at these locations has been released into the atmosphere or flared. However, efforts to expand biogas capture projects are underway. The potential for biogas production from farm waste, landfills and municipal sewage has been estimated to be as much as 3.5 quadrillion BTUS of methane (Natural Gas Vehicles for America, 2011).

3.3.4 The Total Resource

The Potential Gas Committee's most recent assessment of the total domestic natural gas resource base (conventional and unconventional) showed a total of 1,836 TCF, which coupled with 2008 proved reserves of 244.7 TCF, provides for over 100 years of supply at current consumption rates. The 2008 resource estimate was a 39 percent increase of the 2006 estimate. Most of the increase from the previous assessment came from the increasing impact shale gas plays are having on total recoverable numbers (Potential Gas Committee, 2008). Note these resource estimates do not take methane hydrates or biogas into account. The below chart shows the PGC assessment for the past three reporting periods (PGC reports are released every two years.) In only four years, the total assessment jumped 29 percent (2010 estimate over the 2006 estimate.) This is in large part due to the development of shale gas and the contribution these new resources offer total U.S. supply.

Potential Gas Committee Assessment, 2010 (TCF)				
Resource Category	**2006**	**2008**	**2010**	**% Increase since 2006**
Traditional Gas Resources:				
Probable resources (current fields)	270.1	441.4	536.6	50%
Possible resources (new fields)	426.4	736.9	687.7	38%
Speculative resources (frontiers)	460.7	500.7	518.3	11%
Total Traditional Gas Resources*	1154.8	1673.4	1739.2	34%
Coalbed Gas Resources:				
Probable resources	15.5	14.2	13.4	-16%
Possible resources	50.9	49.8	48.1	-6%
Speculative resources	98.9	98.9	96.2	-3%
Total Coalbed Gas Resources*	166.1	163	158.6	-5%
Grand Total Potential Resources**	1320.9	1836.4	1897.8	30%
Proved dry-gas reserves (DOE/EIA):	211.1	244.7	272.5	23%
U.S. Future Gas Supply	1532	2081.1	2170.3	29%
Current Consumption	21.684641	23.268056	24.133037	10%
Supply in Years Based on Current Consumption	70.65	89.44	89.93	21%
*Mean values for Probable, Possible and Speculative resources are *not* arithmetically additive in deriving Total Traditional Gas Resources or Total Coalbed Gas Resources.				
**Mean values for Total Traditional Resources and Total Coalbed Gas Resources are arithmetically additive in deriving Grand Total Potential Resources.				
† Latest available figure is for year-end 2009.				
Note: Totals are subject to rounding and differences due to statistical aggregation of distributions.				
Current Consumption from EIA http://www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm				
Source: Potential Gas Committee, 2011 http://www.potentialgas.org/				

Table 3: Potential Gas Committee Natural Gas Assessment, 2006-2010 (TCF) (Potential Gas Committee, 2008)

EIA elaborates on the increasing role of shale gas in U.S. gas supplies in the figure below. According to EIA, in 2010 shale gas accounted for nearly 23 percent of U.S. natural gas supply, up from just two percent in 2000. EIA predicts that by 2035, shale gas will account for 47 percent of U.S. gas supply (U.S. Energy Information Administration, 2011).

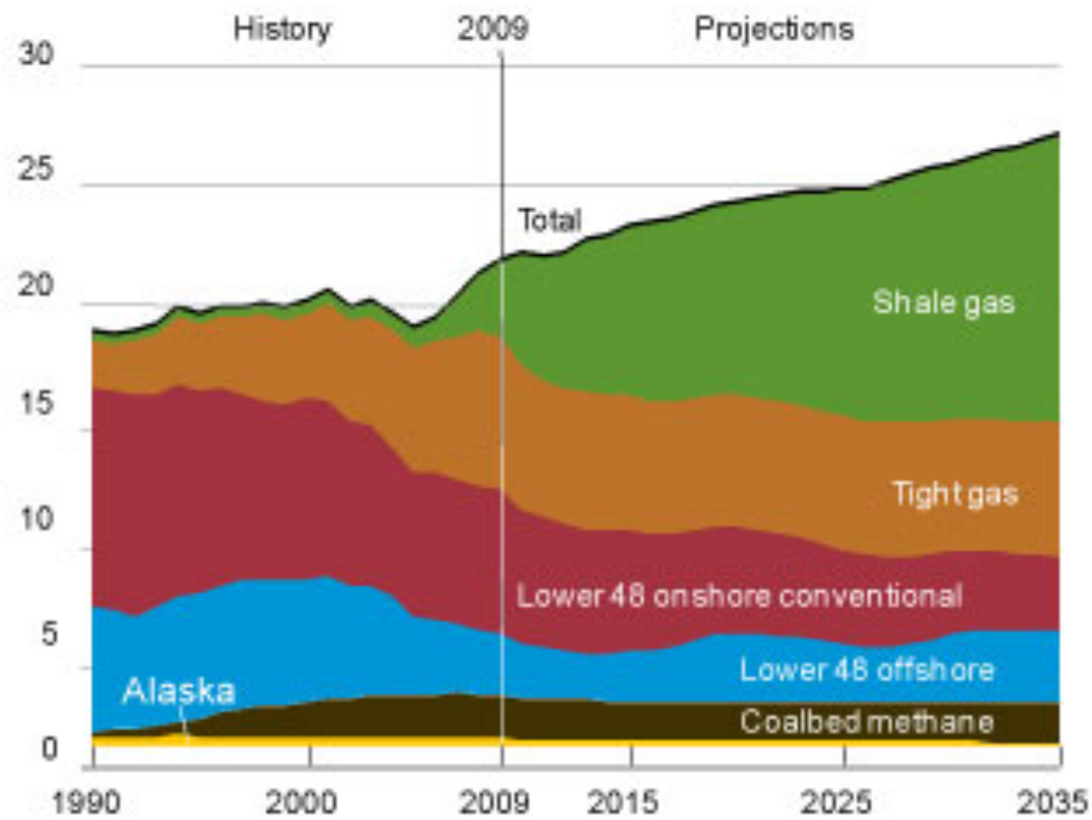


Figure 18: Natural Gas Production by Source, 1990-2035 (U.S. Energy Information Administration, 2011)

3.3.5 Imports

While nearly all of the natural gas consumed in the U.S. is produced domestically (87 percent), there is also a small import market for natural gas mostly from Canada (11 percent), with an even smaller amount arriving through liquefied natural gas (LNG) import terminals (2 percent).

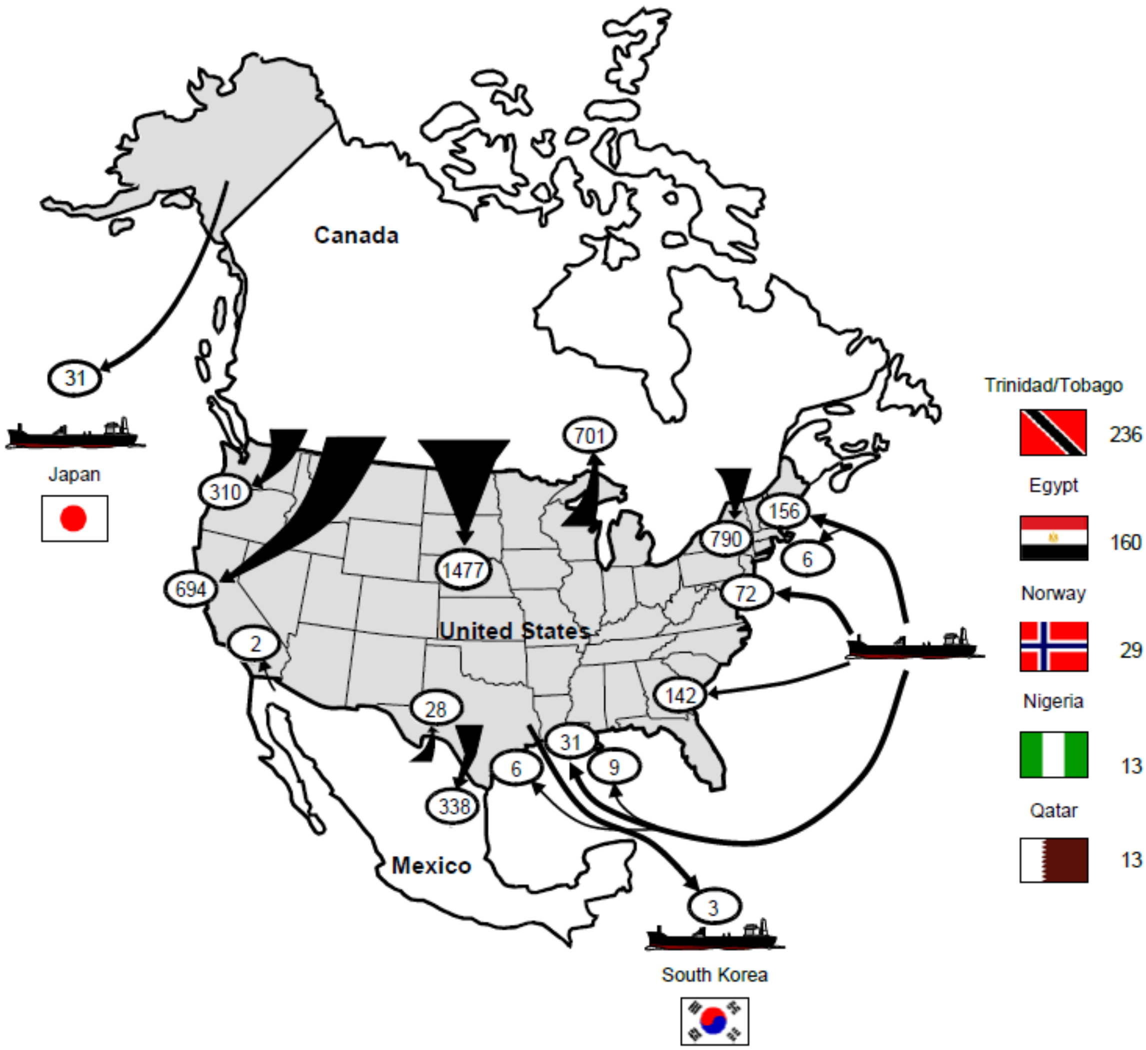


Figure 19: Flow of Natural Gas Imports and Exports, 2009 (Billion Cubic Feet) (U.S. Energy Information Administration, 2010)

In 2009 net imports totaled 2.68 TCF, representing 12 percent of total consumption. The chart below shows net imports (The U.S. exports less than 500 BCF annually to Japan and Mexico) as a percentage of total domestic consumption. A noticeable decline occurs in 2008 and continues in 2009 when net imports reached their lowest level since 1994 (U.S. Energy Information Administration, 2010). While consumption decreased in 2009 with lagging demand due to the economic slowdown, the declining import numbers are also the result of strong domestic production numbers.

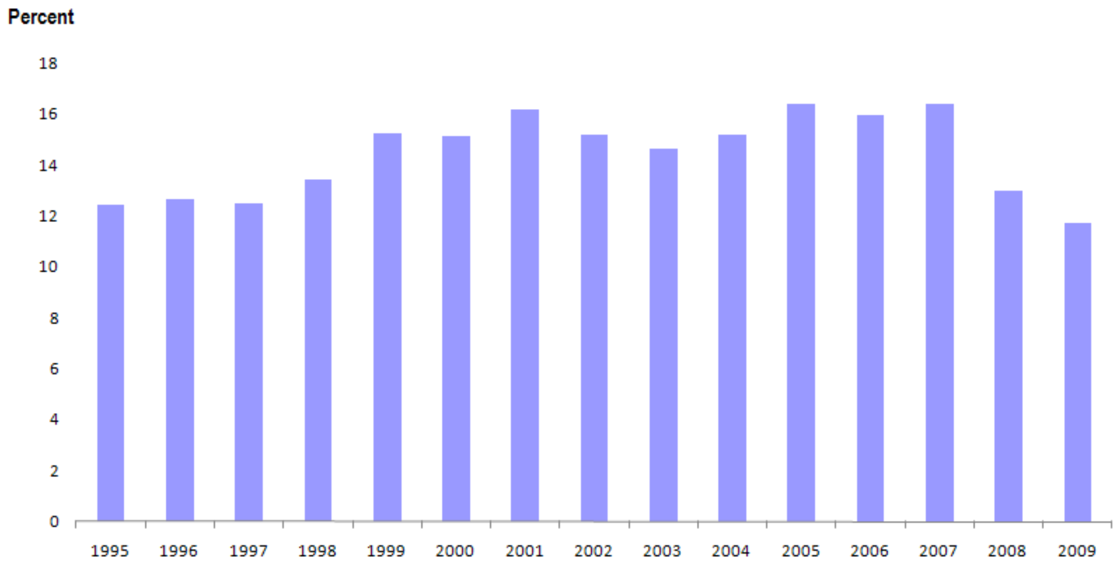


Figure 20: Net Imports as a Percentage of Domestic Consumption, 1995-2009 (U.S. Energy Information Administration , 2010)

3.4 Conclusion

Annually the U.S. consumes nearly 24 TCF of natural gas, demand that is met by both domestic production and, to a lesser degree, imports. Approximately 87 percent is produced domestically with 12 percent coming in via pipeline from Canada and the balance (2 percent) coming in via LNG tankers from other foreign trade partners. The U.S.'s ability to meet the majority of its natural gas demand with domestic production is due to both conventional and unconventional natural gas resources. In the last five years, shale gas discoveries have increased total U.S. gas resource estimates by nearly 30 percent to more than 2,000 TCF. In addition to gas produced from underground reservoirs, methane resources are also available in smaller quantities through the production of biogas. Looking forward, scientists are also studying methane hydrates, which if they can be produced economically, have the potential to bring significant additional natural gas resources online.

Chapter 4: Natural Gas as a Transportation Fuel

Using natural gas as an alternative to traditional vehicle fuels, such as gasoline or diesel, is not a new idea, but the newly understood domestic availability of the resources described in the previous section plus a recent policy push for cleaner fuels has lead to an increased interest in its use as a possible solution to some of the nation's energy challenges. Understanding the benefits that natural gas as a transportation fuel offers while weighing those against disadvantages and challenges to expanded use allows for an assessment of its viability.

4.1 The Fuel

As a transportation fuel, natural gas is most commonly utilized as a gas, in the form of compressed natural gas (CNG), or as a liquid, in the form of liquefied natural gas (LNG). Methanol, a liquid fuel made from methane through a conversion process, is another fuel option. For the purposes of this report, focus will be on CNG as it is the most common form of natural gas utilized for passenger vehicle fuel.

In the case of CNG, natural gas is compressed and dispensed at a high pressure between 3000 psi and 3600 psi. CNG is normally delivered and priced in "gasoline gallon equivalents" (GGE). The term GGE refers to the equivalent amount of energy in an alternative fuel, in this case, CNG relative to gasoline. The U.S. National Institute of Standards and Technology (NIST) has defined one GGE equal to 126.67 cubic feet of natural gas or 5.660 pounds (U.S. National Institute of Standards and Technology, 2007).

Converting alternative fuels to a GGE allows users to easily compare both price and energy content of one fuel to another in a unit of measurement they are already comfortable with. One standard gallon of gasoline has 114,000 BTU/gallon, a measure of its energy content. Similarly, one CNG GGE equals 126.67 cubic feet of natural gas, and each cubic foot has about 900 BTUs of energy content, or 114,003 BTUs. The table below shows the energy content of various fuels. The gallon equivalent describes how much energy each fuel has relative to a gallon of gasoline.

Gasoline Gallon Equivalents			
Fuel Type	**Unit of Measure**	**BTUs/Unit**	**Gallon Equivalent**
Gasoline (regular)	gallon	114,100	1.00 gallon
Diesel #2	gallon	129,500	0.88 gallons
Biodiesel (B100)	gallon	118,300	0.96 gallons
Biodiesel (B20)	gallon	127,250	0.90 gallons
Compressed Natural Gas (CNG)	cubic foot	900	126.67 cu. ft.
Liquid Natural Gas (LNG)	gallon	75,000	1.52 gallons
Propane (LPG)	gallon	84,300	1.35 gallons
Ethanol (E100)	gallon	76,100	1.50 gallons
Ethanol (E85)	gallon	81,800	1.39 gallons
Methanol (M100)	gallon	56,800	2.01 gallons
Methanol (M85)	gallon	65,400	1.74 gallons
Electricity	kilowatt hour (Kwh)	3,400	33.56 Kwhs

Table 4: Gasoline Gallon Equivalents and Energy Content for Various Fuel Types (Gable)

In addition to CNG, natural gas can also be utilized as a transportation fuel in the form of liquefied natural gas (LNG), but this is more commonly used for heavy-duty vehicles and not in passenger vehicles. LNG, which is natural gas cooled to -260 degrees Fahrenheit (at such low temperatures the gas liquefies), has higher energy intensity than CNG, allowing more BTUs to be packed in to smaller spaces. While a GGE of CNG equals the amount of energy in a gallon of gasoline, it's important to realize a GGE of CNG takes up considerably more space than a liquid gallon. One gallon of LNG, on the other hand, takes up the same amount of space as a gallon of any other liquid fuel. The volume of the same energy content of LNG and CNG allows LNG vehicles to travel farther with fewer stops making LNG a better option for heavy-duty, long-range vehicles.

The Massachusetts Institute of Technology (MIT) recently released a study on natural gas as a transportation fuel that also noted the possibility of converting natural gas to liquid fuels, or gas to liquid technologies (GTL). Converting natural gas into a room temperature liquid fuel involves first converting natural gas to a syngas and then converting the gas to a liquid by catalytic conversion. While several fuels can be produced, including methanol and ethanol, MIT focused on methanol. Methanol is an alcohol, which can be used in spark ignition engines, but use of methanol may negate some of the benefits of using methane in the gaseous form, such as reduced CO2 emissions and the significant fuel cost savings of CNG and LNG over gasoline or diesel (Massachusetts Institute of Technology, 2010). According to the study:

> "Energy density, ease of use and infrastructure considerations make liquid fuels that are stable at room temperature a compelling choice in the Transportation sector. The chemical conversion of natural gas to liquid fuels could provide an attractive alternative to CNG. Several pathways are possible, with different options yielding different outcomes in terms of total system CO2 emissions and cost. Conversion of natural gas to methanol, as widely practiced in the chemicals industry, could provide a cost-effective route to manufacturing an alternative, or supplement, to gasoline, while keeping CO2 emissions at roughly the same level. Gasoline engines can be modified to run on methanol at modest cost," (Massachusetts Institute of Technology, 2010).

The below table describes various characteristics of multiple fuel options, including traditional gasoline, diesel, ethanol, propane as well as natural gas based fuels such as CNG, LNG and methanol, as mentioned above.

Property	Gasoline	No. 2 diesel	Methanol	Ethanol
Chemical formula	C_4 to C_{12}	C_3 to C_{25}	CH_3OH	C_2H_5OH
Physical state	Liquid	Liquid	Liquid	Liquid
Molecular weight	100–105	≈200	32.04	46.07
Composition (weight %)				
Carbon	85–88	87	37.5	52.2
Hydrogen	12–15	13	12.6	13.1
Oxygen	0	0	49.9	34.7
Main fuel source(s)	Crude oil	Crude oil	Natural gas, coal, or woody biomass	Corn, grains, or agricultural waste
Specific gravity (60° F/ 60° F)	0.72–0.78	0.85	0.796	0.796
Density (lb/gal @ 60° F)	6.0–6.5	7.079	6.63	6.61
Boiling temperature (F°)	80–437	356–644	149	172
Freezing point (F°)	-40	-40–30	-143.5	-173.2
Autoiginition temperature (F°)	495	≈600	867	793
Reid vapor pressure (psi)	8–15	<0.2	4.6	2.3

Property	Propane	CNG	Hydrogen
Chemical formula	C_3H_8	CH_4	H_2
Physical state	Compressed gas	Compressed gas	Compressed gas or liquid
Molecular weight	44.1	16.04	2.02
Composition (weight %)			
Carbon	82	75	0
Hydrogen	18	25	100
Oxygen	n/a	n/a	0
Main fuel source	Underground reserves	Underground reserves	Natural gas, methanol, and other energy sources
Specific gravity (60° F/ 60° F)	0.508	0.424	0.07
Density (lb/gal @ 60° F)	4.22	1.07	n/a
Boiling temperature (F°)	-44	-263.2 to -126.4	-423
Freezing point (F°)	-305.8	-296	-435
Autoiginition temperature (F°)	842	900-1,170	932
Reid vapor pressure (psi)	208	2,400	n/a

Table 5: Properties of Conventional and Alternative Fuels (Davis, Diegel, & Boundy, 2010)

4.2 Benefits

This section evaluates some of the benefits of utilizing compressed natural gas, including reduced operating costs.

4.2.1 Reduced Operating Costs

Perhaps the most compelling arguments for NGVs are the overall operating cost savings through both reduced fuel and maintenance costs. The cost impacts are detailed below.

4.2.1.1 Maintenance Costs

Because natural gas engines work essentially the same way as gasoline engines (an air-fuel mixture is injected into the intake manifold, drawn into the combustion chamber, and then ignited by a sparkplug), most engine service issues are very similar and can be handled by a dealer or automotive shop. The cleaner nature of the fuel also results in reduced build up over time, extending the time needed between oil changes for example (NGVAmerica).

In a study conducted by the U.S. Department of Energy (DOE) in 1999, researchers compared maintenance costs for CNG and gasoline powered vehicles in a taxi fleet. After a side-by-side analysis, the study found that it costs approximately 15 percent less to maintain the CNG taxis (Transportation and Regional Programs Division, 2002).

4.2.1.2 Fuel Costs

The price of CNG is calculated based on the cost of the natural gas plus any processing and delivery costs. Similar to the link between gasoline prices and crude oil prices, the retail price of CNG is linked to the raw commodity price of natural gas, a price that on an energy equivalent basis enjoys a significant discount.

Because the raw feedstock is a key component in the final retail fuel product, the commodity price outlook for natural gas relative to crude oil, the feedstock for gasoline, explains much of the lower retail price. The below figure compares the EIA forecasted price for oil versus natural gas through 2035 on a $/MMBTU basis. As evident from the consistent discrepancy between the two price curves, natural gas is expected to continue to trade at a significant discount to oil.

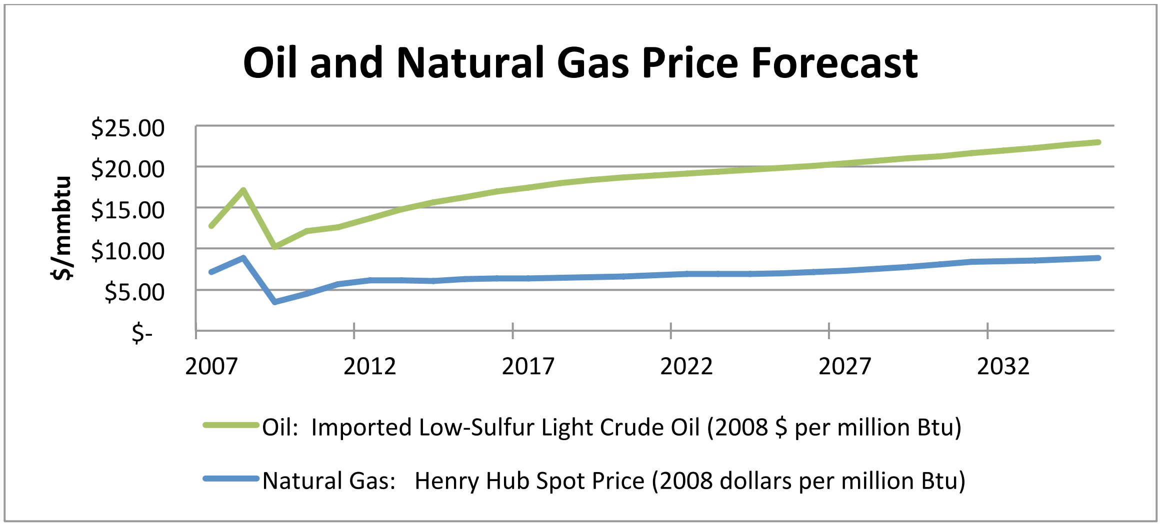


Figure 21: Raw Commodity Cost Comparison of Oil and Natural Gas (U.S. Energy Information Administration, 2010)

According to investment house, Raymond James, "it's materially cheaper to produce a gallon of CNG than a gallon of gasoline" (Molchanov & Garcia, 2010).

Given the significant spread between oil and natural gas on an energy equivalent basis (for example, the average price for petroleum in the first half of 2011 was $16.96 per million BTU (MMBTU), which is nearly four times higher than the average price for natural gas over the same period at $4.27 per MMBTU).

A general rule of thumb suggests one MCF (thousand cubic feet) of gas yields eight gallons of CNG after compression with energy content of approximately 1 MMBTU. Using the average price for the first half of 2011, of $4.27 MMBTU, yields a base commodity cost of $0.53/compressed gallon or $0.53/MMBTU. Compare this price to the raw numbers for gasoline: a barrel of oil yields about 42 gallons, meaning at $98.38/barrel (the average price for the first half of 2011), the raw commodity cost for gasoline is $2.34/gallon, or $16.96 per MMBTU.

Retail prices include more than just the feedstock, however. In fact, processing costs are higher per gallon of CNG than gasoline at approximately $1.00/GGE of CNG compared to $.20/gallon of gasoline, which could offset some of the feedstock savings (Molchanov & Garcia, 2010).

Nonetheless, CNG still comes out lower than gasoline after additional costs are combined when considered against Raymond James' current-year price forecasts as displayed by the figure below with an all-in, pre-tax, "leaving the refinery" cost of $1.53/gallon, vs. gasoline at $2.14/gallon – a savings of approximately 30 percent. This is only an estimate, "because a barrel of crude oil produces a mix of various refined products – gasoline, diesel, residual fuel, etc. – not all of which compete directly with CNG. In addition, government incentives, taxes, distribution costs, and profit margins are not taken into account here" (Molchanov & Garcia, 2010).

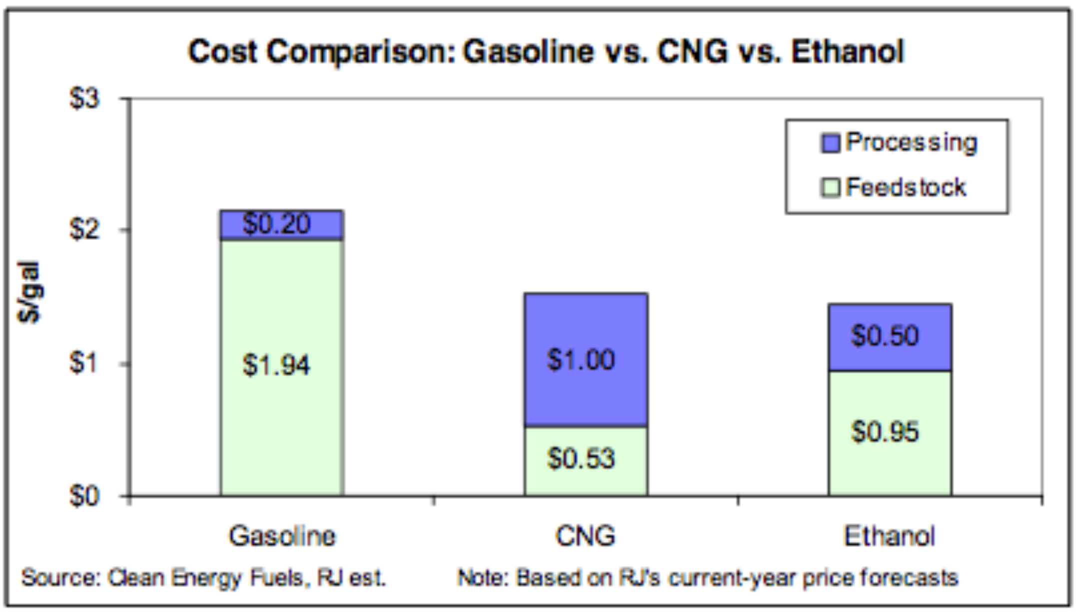


Figure 22: Cost Comparison: Gasoline vs. CNG vs. Ethanol (Molchanov & Garcia, 2010)

As of April 2011, CNG retailed for nearly 30 percent less than gasoline. According to the U.S. Department of Energy, average national prices for CNG were $2.06 a GGE and $3.69 a gallon for gasoline (Clean Cities, 2011).

	Nationwide Average Price for Fuel This Report	Nationwide Average Price for Fuel Last Report	Change in Price This Report vs. Last Report	Units of Measurement
Gasoline (Regular)	$3.69	$3.08	$0.61	per gallon
Diesel	$4.04	$3.45	$0.59	per gallon
CNG	$2.06	$1.93	$0.13	per GGE
Ethanol (E85)	$3.20	$2.75	$0.45	per gallon
Propane	$3.19	$3.05	$0.14	per gallon
Biodiesel (B20)	$4.05	$3.50	$0.55	per gallon
Biodiesel (B99-B100)	$4.32	$4.05	$0.27	per gallon

Table 6: Overall Average Fuel Prices, April 2011 (Clean Cities, 2011)

Comparing CNG average retail prices over the last ten years to not only gasoline but also propane, E85, biofuels and diesel shows not only a lower price curve but also a less volatile trend as shown in the below figure (Alternative Fuels & Advanced Vehicles Data Center, 2011).

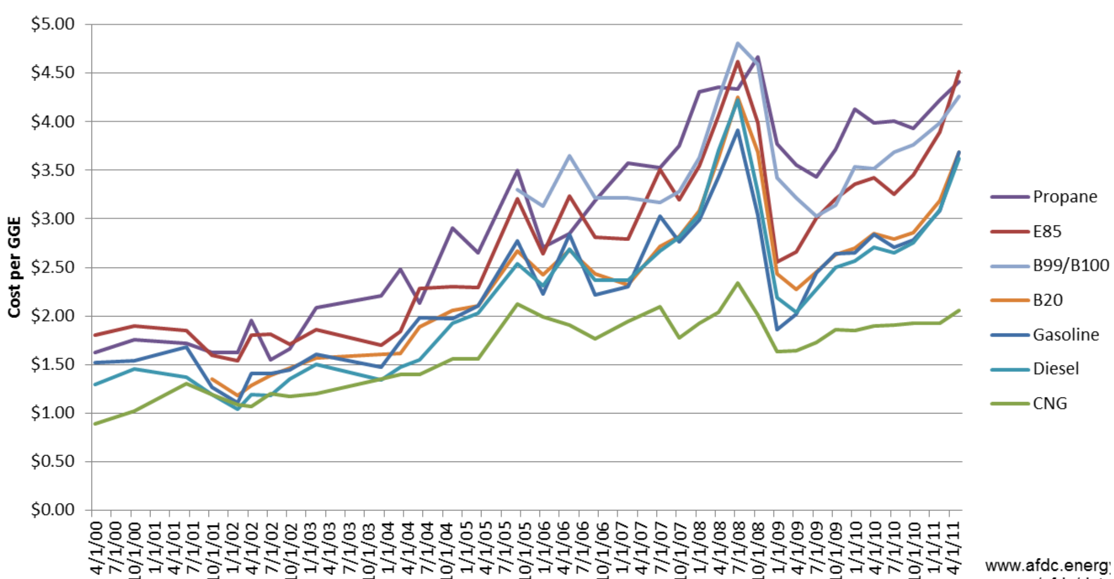


Figure 23: U.S. Average Retail Fuel Prices, 2000-2011 (Alternative Fuels & Advanced Vehicles Data Center, 2011)

4.2.2 Fuel Economy Benefits

While not as significant, some data suggests original equipment manufacturer (OEM) CNG-powered vehicles might also experience improved fuel efficiency of approximately 1 percent. The improved fuel economy of gaseous fuels, such as CNG, combusted in a spark ignition (SI) ICE, is because of a higher compression ratio. However, researchers point out that in bi-fuel applications as well as after-market conversions, this improved efficiency is most likely not realized (Hekkert, Hendricks, Faaij, & Neelis, 2005).

Other research suggests the improved fuel economy might be negligible. In the above referenced study undertaken by DOE of a taxicab fleet, the recorded fuel economy of the CNG-powered and gasoline-powered taxis were the same (Transportation and Regional Programs Division, 2002).

In a later discussion of the on-road NGV experiment undertaken as part of the research for this paper, an improved fuel economy was also experienced and will be elaborated on in detail in Chapter 5.

4.2.3 Emissions Benefits

Another attractive and commonly touted benefit of natural gas vehicle fuels is the reduced emissions as a result of combustion. The cleaner, simpler nature of the fuel results in a reduction in carbon dioxide, carbon monoxide, sulfur dioxide, nitrous oxide, and particulate matter emissions, which can have not only air quality implications but related health effects.

As displayed by the below figure, transportation emissions are a significant contributor to overall carbon monoxide, NOx and VOC emissions – predecessors for smog, underscoring the opportunity to impact overall emissions by addressing the transportation sector.

Sector	CO	NOx	VOC	PM-10	PM-2.5	SO_2
Highway vehicles	**38.87**	**5.21**	**3.42**	**0.17**	**0.11**	**0.06**
	50.0%	*31.9%*	*21.5%*	*1.2%*	*0.1%*	*0.6%*
Other off-highway	**18.04**	**4.26**	**2.59**	**0.30**	**0.28**	**0.46**
	23.2%	*26.0%*	*16.2%*	*2.1%*	*5.1%*	*4.0%*
Transportation total	**56.90**	**9.46**	**6.00**	**0.48**	**0.39**	**0.52**
	73.2%	*57.9%*	*37.7%*	*3.2%*	*7.2%*	*4.5%*
Stationary source fuel combustion	**5.28**	**5.57**	**1.45**	**1.33**	**1.03**	**9.80**
	6.8%	*34.1%*	*9.1%*	*9.0%*	*19.0%*	*85.7%*
Industrial processes	**2.18**	**0.93**	**6.77**	**1.17**	**0.48**	**1.00**
	2.8%	*5.7%*	*42.5%*	*7.9%*	*8.8%*	*8.7%*
Waste disposal and recycling total	**1.58**	**0.12**	**0.37**	**0.29**	**0.27**	**0.03**
	2.0%	*0.7%*	*2.3%*	*1.9%*	*4.9%*	*0.2%*
Miscellaneous	**11.73**	**0.26**	**1.33**	**11.54**	**3.28**	**0.09**
	15.1%	*1.6%*	*8.4%*	*77.9%*	*60.2%*	*0.7%*
Total of all sources	**77.69**	**16.34**	**15.93**	**14.81**	**5.45**	**11.43**
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 7: Total Emissions of Criteria Air Pollutants by Sector, 2008 (millions of short tons/percentages) (U.S. Department of Energy, 2011)

As discussed in Chapter 3, the key component of natural gas, methane, has a simple molecular structure with only one carbon atom and four hydrogen atoms compared with the molecular structure of isooctane (typical molecule of gasoline), which has a complex chain of eight carbon atoms and 18 hydrogen atoms (Fuel Chemistry, 1998). The simple molecular structure and fewer carbon atoms result in less carbon dioxide emissions at combustion.

While natural gas vehicles may have higher methane emissions than gasoline-fired vehicles, the carbon dioxide reduction more than offsets any potential methane emissions (NGVAmerica, 2011). In fact, all things considered, in a well-to-wheel analysis, NGVs produce about 22 percent less GHGs than burning diesel and 29 percent less than burning gasoline (Kolodziej, 2010).

According to DOE, emissions benefits extend beyond carbon dioxide, however. While actual emissions will vary with engine design, carbon monoxide emissions are reduced by 90 to 97 percent, nitrogen oxide (NOx) emissions are reduced by 35 to 60 percent, fewer toxic, carcinogenic, and particulate emissions are realized, and, in dedicated vehicles, DOE analysis found no evaporative emissions (Transportation and Regional Programs Division, 2002).

In fact, the first vehicles certified by the U.S. Environmental Protection Agency (EPA) to meet the ultra-low emission, super-ultra low-emission standards were NGVs. In 2009, the natural gas-fueled Honda Civic GX was even named the "Greenest Car in America" by the American Council for an Energy-Efficient Economy for the seventh year in a row (Kolodziej, 2010).

The National Academy of Sciences (NAS) attempted to quantify the life cycle implications of various alternative fuels in a 2010 report entitled "Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use". In the section on transportation fuels, the report looked at both non-climate-change damages and GHG emissions associated with light-duty vehicles. Among the findings, the report concluded,

> With further expected improvements in vehicle technology and fuel efficiency, natural gas powered vehicles will provide superior benefits in terms of criteria pollutant reductions compared to nearly all other types of vehicles, even electric and plug-in hybrid electric vehicles.

According to the NAS report, it is estimated that, in 2005, the light-duty vehicle sector produced $36 billion in health and other non-climate-change damages, which were expressed in vehicle-miles traveled (VMT) and ranged from 1.2 cents to 1.7 cents for varying fuels. The life cycle costs considered four stages including vehicle operation (tailpipe and evaporative emissions), the production and transportation of the fuel feedstock, the refining process, and the manufacturing of the vehicle (National Research Council of the National Academies, 2010).

The non-climate change damages, which included health and environmental impacts, found CNG, E85, and certain hybrid electric vehicles as producing the lowest damages over the life-cycle of the fuel, as shown in the figure below, with the summed totals for 2005 and 2030 summarized in the following table.

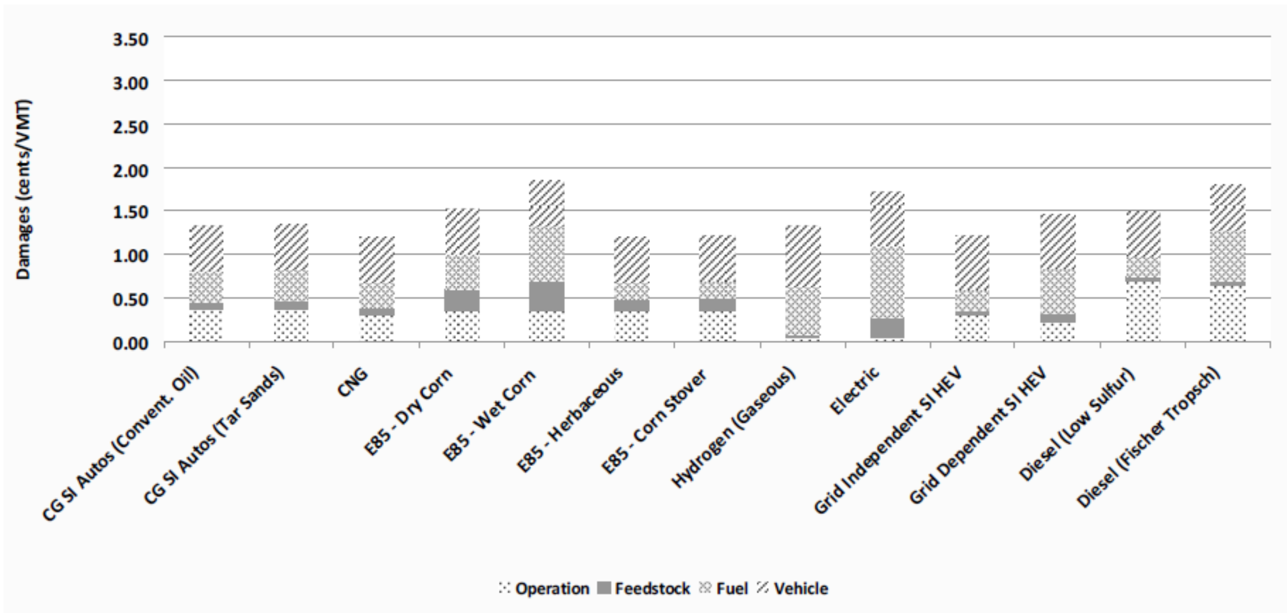


Figure 24: Health and Other Damages by Life Cycle Component for LD Vehicles (National Research Council of the National Academies, 2010)

Category of Aggregate Damage Estimates (Cents/VMT)	2005	2030
1.10-1.19		CNG Diesel with low sulfur and biodiesel
1.20-1.29	E85 herbaceous E85 corn stover CNG Grid-independent HEV	E85 corn stover E85 herbaceous
1.30-1.39	Conventional gasoline and RFG E10 Hydrogen gaseous	Conventional gasoline and RFG E10 E85 corn
1.40-1.49	Diesel with low sulfur and biodiesel Grid-dependent HEV	Electric vehicle
1.50-1.59	E85 corn	Grid-independent HEV Grid-dependent HEV
>1.60	Electric vehicle	Hydrogen gaseous

Table 8: Health and Other Damages for LD Vehicles (National Research Council of the National Academies, 2010)

4.3 SUMMARY OF DRAWBACKS

While the benefits of natural gas as a transportation fuel for passenger vehicles are many, there are existing drawbacks that are preventing market penetration, including vehicle costs and limited options, limited range and tank size, a lack of refueling infrastructure, and perceived safety concerns.

Many of the benefits discussed above have been well-documented for decades, yet the challenges to greater market penetration continue to plague the prospects of natural gas vehicles. In the 1970s following the oil embargo, interest in alternative fuels, such as natural gas, increased, as it did in the 1990s, yet it soon dissipated for what CERA claims are three main hurdles the industry was never able to fully overcome: fueling infrastructure, driving range and cost. In addition to these drawbacks, lingering concerns exist also exist related to limited vehicle options and perceived safety concerns (IHS CERA, 2010).

4.3.1 Limited Vehicle Options and High Costs

4.3.1.1 Limited Vehicle Options

Over 50 different manufacturers produce 150 models of light, medium and heavy-duty vehicles and engines. In the passenger vehicle market domestically, however, options are limited. In the United States, there are essentially two options for passenger vehicle, either purchase a new OEM CNG powered vehicle or convert an existing gasoline powered vehicle.

OEM models are few and far between in the United States. Currently, the Honda Civic GX is the only true passenger vehicle option available. There are additional potential passenger options in the works. General Motors (GM), for example, recently announced plans to develop and sell a CNG van option, which will most likely be adopted by the fleet vehicle market (Plautz, 2010). The Vehicle Production Group (VPG), a relatively new automotive manufacturing firm, is also in the process of producing a CNG van, the MODI 1. The target market for the MODI 1 will be the taxi market but theoretically could be used as a passenger vehicle, particularly as it can be equipped with wheelchair access (Boyd, 2010).

Many auto manufacturers currently produce CNG passenger vehicles; however, they are not available for purchase in the U.S. CNGNow.com maintains a gallery of passenger CNG vehicles available in other parts of the world. Examples include Chevrolet, Ford, Mercedes and VW options. Without sufficient demand for CNG passenger vehicles in the U.S., they will more than likely not offer the option. It is important to note, however, the technology exists, and if and when the manufacturers feel confident the vehicles would sell, plans for U.S. distribution may be revisited.

Until passenger vehicle purchasers have additional options, another option is the after-market conversion to CNG of gasoline-powered passenger vehicles. The conversion process involves altering the vehicle after purchase with the addition of a CNG conversion kit to either a dedicated CNG engine or a bi fuel option.

Not all vehicles, however, have a certified conversion kit available. Kits must go through rigorous and expensive testing before being certified to comply with U.S. emissions standards. Under the Clean Air Act, the U.S. Environmental Protection Agency (EPA) has the authority to regulate vehicle emissions and requires after market conversion kit manufacturers to certify that the systems meets emissions standards. Failure to comply with this requirement can result in significant fines because it is otherwise illegal to tamper with a vehicle's emission system (NGVAmerica, 2011).

NGVAmerica, a natural gas vehicle trade association, maintains an up to date list of current conversion kits offered for various vehicle models. According to NGVAmerica, there are approximately 12 manufacturers offering EPA-certified systems for a variety of dozen GM and Ford light-duty "engine families" covering about 40 vehicle models (NGVAmerica, 2011).

4.3.1.2 High Vehicle Costs

As discussed in the section on benefits, NGV drivers will experience reduced operating costs in the form of lower fuel and maintenance costs, but the vehicles themselves are more expensive than their gasoline counterparts. These additional up front costs comprise one of the most significant hurdles to greater NGV adoption.

The higher cost for OEM vehicles, such as the Honda Civic, can be attributed to several factors, including the cost of the CNG storage tanks and the low production volumes. CNG tanks must be manufactured to safely hold the highly pressurized gas. There are various materials such as metals and composite materials that may be employed for tank manufacturing. While both are equally safe, metal tanks are cheaper to construct but significantly heavier than composite tanks (Gambone, 2005). When one considers the standard gasoline tank is a smaller and simpler shaped, steel container, the higher cost for cylinder CNG tanks made to hold high pressurized gas is understandable.

The higher incremental cost for OEM passenger vehicles is apparent in the Civic GX MSRP pricing. For the 2010 model year, the Honda Civic GX was approximately $6,800 more than the comparable gasoline-powered Honda Civic.

In addition to the higher component costs, like the fuel storage tanks, another reason for the higher cost of the Civic is also more than likely the small volumes Honda is currently producing. In 2010, Honda only sold 2,000 Civic GXs in the U.S. Some vehicle experts predict that if demand for the vehicles increases, reduced costs and therefore lower retail prices may be realized through economies of scale.

Higher costs are also implicit in after-market conversions. Passenger vehicles that employ a CNG conversion kit must first pay the gasoline-powered vehicle cost and then pay for the conversion kit and installations costs. Kit prices vary by vehicle but can run between $6,000 and $12,000 (NGVAmerica, 2011).

4.3.2 Vehicle Drawbacks: Tank Size and Range

Another drawback of NGVs is related to the nature of the gaseous fuel, characteristics discussed in Chapter 3. Because gases, even compressed, take up more volume than liquid fuels of similar energy content, the fuel needed onboard an NGV can take up valuable space. In the For example, the standard Honda Civic has a trunk capacity of 12.5 cubic feet (American Honda Motor Co., 2011), but due to the size of the CNG tank, which is stored and mounted in the trunk area, the Honda Civic GX remaining trunk space is only six cubic feet (American Honda Motor Co., 2011), meaning the tank alone takes up over half of the traditional trunk space of a Honda Civic. In certain after-market conversion options, such as certain light duty trucks and SUVs, CNG tanks can be mounted in the undercarriage of the vehicle causing less of a space inconvenience.

In addition to the tank space requirements, the Civic GX tank only has a CNG capacity of 7.8 GGEs (American Honda Motor Co., 2011), compared to the standard gasoline tank in a civic, which has a tank of 13.2 gallons (American Honda Motor Co., 2011). So while the gasoline and CNG Civics may experience similar fuel economy, with less CNG on board, GX drivers experience a shorter range on a full tank of CNG relative to full tank of gasoline.

Conditions when fueling can affect the fill of the tank. The CNG is pressurized to 3600 psi at 70 degrees Fahrenheit. As the ambient temperature fluctuates, however, the pressure will also change. The below figure shows the linear relationship between temperature and pressure of stored CNG in the tanks. If, for example, an NGV is refueled in the heat of the day, the temperature of the gas could be higher than 70 degrees and will reach 3600 psi more quickly. As it cools in the tank, overnight for example, the gas will contract and the pressure will drop, freeing up more space in the tank for additional gas.

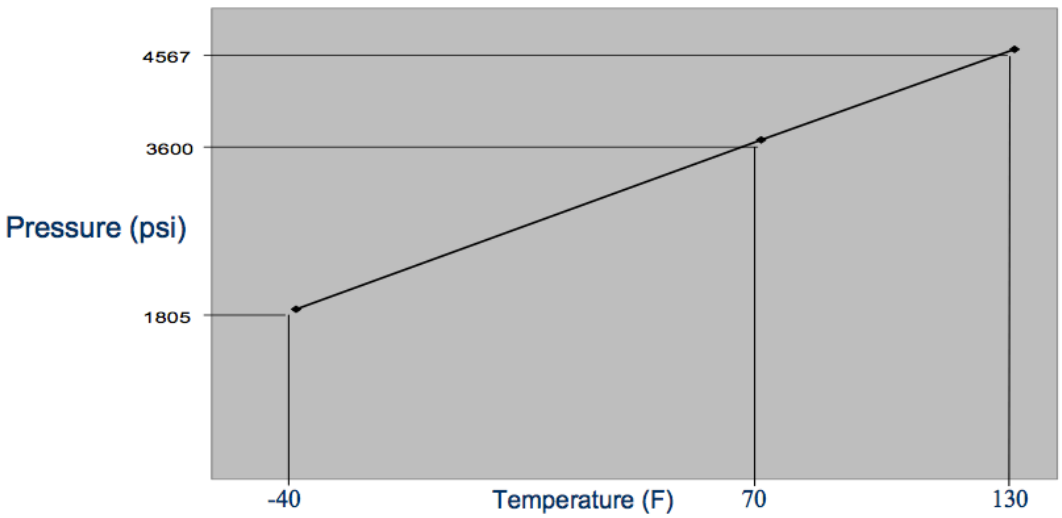


Figure 25: The Relationship Between Pressure and Temperature for CNG (Gambone, 2005)

Interestingly, there are several ways to maximize a fill when refueling an NGV. Temperatures affect the pressure of gas; as it gets warmer, pressure increases. The refueling process itself can generate heat and raise the temperature of the gas being pumped into the vehicle tank. Typically, CNG fills occur at 3,600 psi, but because it's delivered at an elevated temperature, after refueling, the temperature cools and the pressure drops. In order to prevent under fills, PowerTech, a Canadian energy-consulting firm, recommends filling the tanks slowly over time to allow the heat to dissipate. As the temperature lowers and the pressure drops, users will be able to add more fuel to the tank. In addition, PowerTech notes that tanks can be pressured beyond 3,600 psi so that once the gas cools; the pressure will drop and result in something closer to 3,600.

4.3.3 Perceived Safety Concerns

Another potential challenge for greater use of NGVs is the possibility that potential users will be fearful of the fuel, a flammable, pressurized gas. Yet, a review and understanding of CNG safety can help to alleviate safety concerns.

The naturally convenient flammability of natural gas (which is why it's an effective fuel) also presents a risk. However, some of the basic aspects of natural gas might even make it safer than gasoline. Natural gas is lighter than air, which means that when released into the atmosphere, it quickly dissipates (compared with gasoline, which can pool on the ground after an accident, leak or spill, presenting a hazard that doesn't float away by itself very quickly. While natural gas is flammable, it's a non-toxic substance.

Its flammability, however, requires specific conditions. It has a high ignition temperature of 1,000°-1,100°F, compared to a gasoline ignition temperature of 495°. In order for natural gas to ignite, it also has to be at certain saturation in the air with a limited air/fuel combustion ratio of 5-15 percent.

Several safety precautions exist to ensure safe use of CNG. The National Highway Traffic Safety Administration requires CNG fuel tanks meet federal safety standards to ensure tank integrity (49 CFR 571.304). Tanks are required to undergo multiple tests, which include pressure cycling to mimic multiple refueling over time, hydrostatic burst test to ensure the containers do not leak or burst, and bonfire testing to ensure integrity in the event of a fire (Code of Federal Regulations).

Tanks are also required to have built-in fire protection with thermally activated pressure relief devices (PRD) (Gambone, 2005).

Federal regulations further require CNG cylinders have a label detailing the date of manufacture and the date the cylinder must be removed from service, usually 15-20 years. The tanks must also be inspected every 36,000 miles or 3 years (whichever comes first) and must be inspected after vehicles accidents or fires (NGVAmerica).

4.3.4 Limited Refueling Infrastructure

Perhaps the most commonly discussed challenge for NGVs is the limited availability of refueling infrastructure. Without the assurance that users will be able to easily find refueling stations, they are unlikely to make the decision to switch to natural gas.

In general, two main options exist for refueling passenger natural gas vehicles: public access refueling stations and home fueling devices. Public infrastructure is similar to current gasoline station infrastructure, where users can utilize a public pump and pay at the time of the transaction. Home fueling involves the installation of a home fueling device, which connects to a residential gas line and acts like any other home gas appliance.

4.3.4.1 Public Refueling Infrastructure

One of the greatest drawbacks of CNG fuel utilization is the small number of CNG refueling stations. When compared to gasoline stations, passenger vehicles have significantly fewer options. It is estimated that nearly 120,000 gasoline stations can be found across the country making gasoline refueling convenient and easy to find. On the other hand, CNG stations number less than 1,000, with many of those not even open to the public for use. The below chart shows station infrastructure by state for a variety of alternative fuels, including CNG, LPG, Electric, LNG, Hydrogen, E85 and biodiesel.

STATE	CNG	Gasoline
Alabama	5	5,500
Alaska	2	460
Arizona	31	2,190
Arkansas	5	3,300
California	221	9,857
Colorado	29	2,300
Connecticut	14	1,475
Delaware	1	384
Dist. of Columbia	2	121
Florida	16	9,217
Georgia	17	7,685
Hawaii	0	328
Idaho	7	847
Illinois	25	5,100
Indiana	9	1,684
Iowa	0	2,658
Kansas	2	2,500
Kentucky	0	3,507
Louisiana	8	4,082
Maine	1	1,436
Maryland	7	2,346
Massachusetts	20	2,700
Michigan	15	5,076
Minnesota	1	3,656
Mississippi	1	3,559
Missouri	9	4,312
Montana	3	900
Nebraska	3	1,542
Nevada	10	1,094
New Hampshire	3	800
New Jersey	20	3,301
New Mexico	10	1,478
New York	100	7,050
North Carolina	19	7,052
North Dakota	2	930
Ohio	8	4,935
Oklahoma	62	3,500
Oregon	12	1,724
Pennsylvania	24	4,678
Rhode Island	5	375
South Carolina	4	3,924
South Dakota	0	1,073
Tennessee	6	4,713
Texas	33	16,500
Utah	71	1,104
Vermont	3	621
Virginia	9	4,650
Washington	15	3,228
West Virginia	0	1,300
Wisconsin	16	4,126
Wyoming	7	598
Totals By Fuel:	**893**	**167,476**

Table 9: CNG versus Gasoline Refueling Stations By State (Alternative Fuels Data Center, 2011), (Alternative Fuels Data Center, 2011)

The issue of public access is a key concern for passenger vehicle development. While the chart above lists 893 CNG stations across the United States, many of those are on private property and designed to only service private fleet vehicles. The number open to the public is actually much smaller.

The most comprehensive list of CNG stations in the U.S. is available from the U.S. Department of Energy at the following web site: http://www.eere.energy.gov/afdc/fuels/natural_gas_stations.html Here you can retrieve contact information and directions for each station.

4.3.4.2 Home Refueling Infrastructure

In addition to traditional public refueling infrastructure, if a residence has an existing natural gas pipeline connection, the installation of a home fueling device is also a possibility.

Home refueling gives the consumers an added advantage of no longer needing to go to a local fueling station to refuel their car, a convenience many consumers enjoy (NGVAmerica, 2011). The appliances work similar to other home gas appliances, such as a dryer or water heater, and connect to the same supply line. The gas comes in to the appliance and can be compressed on site.

In addition to the added convenience that this option offers the passenger vehicle market, gas would be purchased through the local gas utility equating to even lower rates than published CNG retail rates. Gas usage for a home fueling device would be added to a residential account's existing natural gas usage bill and billed at the residential rate. According to CenterPoint Energy based in Houston, TX natural gas rates would translate to cheap CNG prices per GGE. Based on rates for July 2011, the residential natural gas rates are $6.3755 per MCF, and assuming there are eight 8 gallons per MCF, translates to $0.797 per GGE of CNG. Compression of the gas by the home fueling device also requires electricity. CenterPoint estimates 1.5 kWh of electricity are needed to compress 1 GGE of CNG, which at a current rate of $0.10per Kwh, an additional electricity cost of $.15nfor compression. When they figure in federal taxes of $.18 per gallon, CenterPoint estimates residential users in the Houston area should expect to pay the equivalent of $1.12 per GGE of CNG (Stiff, 2011).

These devices have, however, proved expensive and difficult to come by. The installed cost of a home fueling device is estimated between $5,500 and $6,500 (IHS CERA, 2010). Historically, the only home refueling device on the market has been the Phill, manufactured by BRC FuelMaker (IMPCO Automotive, 2011).

DOE's National Renewable Energy Laboratory (NREL) completed a safety assessment of natural gas home fueling appliances in 2005, specifically focusing on the Phill. The study found that an individual is 10 times more likely to be struck by lightning than to experience a non-misuse deflagration, or a flame, which can range from small flash fires to an explosion. It was further concluded most incidents were more likely to occur in the first year after installation of Phill. Interestingly, even if the device is purposefully misused (e.g., attempting to use Phill to inflate a pool toy), a user is still more than twice as likely to be struck by lightning than for Phill to cause a deflagration. Fires resulting from use of the home fueling device are even less likely to occur (National Renewable Energy Laboratory, 2005). The results of the NREL analysis are included in the figure below.

Phill-Related Incidents	**Annual Probability**
Deflagration, all non-misuse failures	1 in 7,000,000
Deflagration, all misuse failures	1 in 1,400,000
Structure fire, all non-misuse failures	1 in 14,600,000
Structure fire, all non-misuse failures	1 in 10,700,000
Other incidents (Not Related to Phill)	**Annual Probability**
Residential structure fire	1 in 300
Being killed in a vehicle crash	1 in 6,800
Being struck by lghtning	1 in 686,000
Electrocution by a consumer product	1 in 1,880,000

Table 10: Calculated Probabilities of Phill-Related Safety Incidents (National Renewable Energy Laboratory, 2005)

In addition to the Phill, there are other models being developed, including a device under development by NatGasCar, LLC, the Ecowise. It is anticipated the device will fuel twice as fast as the Phill, at a rate of one GGE per hour, although pricing data has not yet been released on the product's website (NatGasCar, LLC, 2011).

4.4 NGV Incidence

While there are nearly 13.25 million NGVs worldwide, there are only 110,000 NGVs in the U.S. (NGV Journal, 2010). The chart below shows the U.S. lagging in comparison to countries such as Argentina, Brazil, Pakistan, Italy, and India.

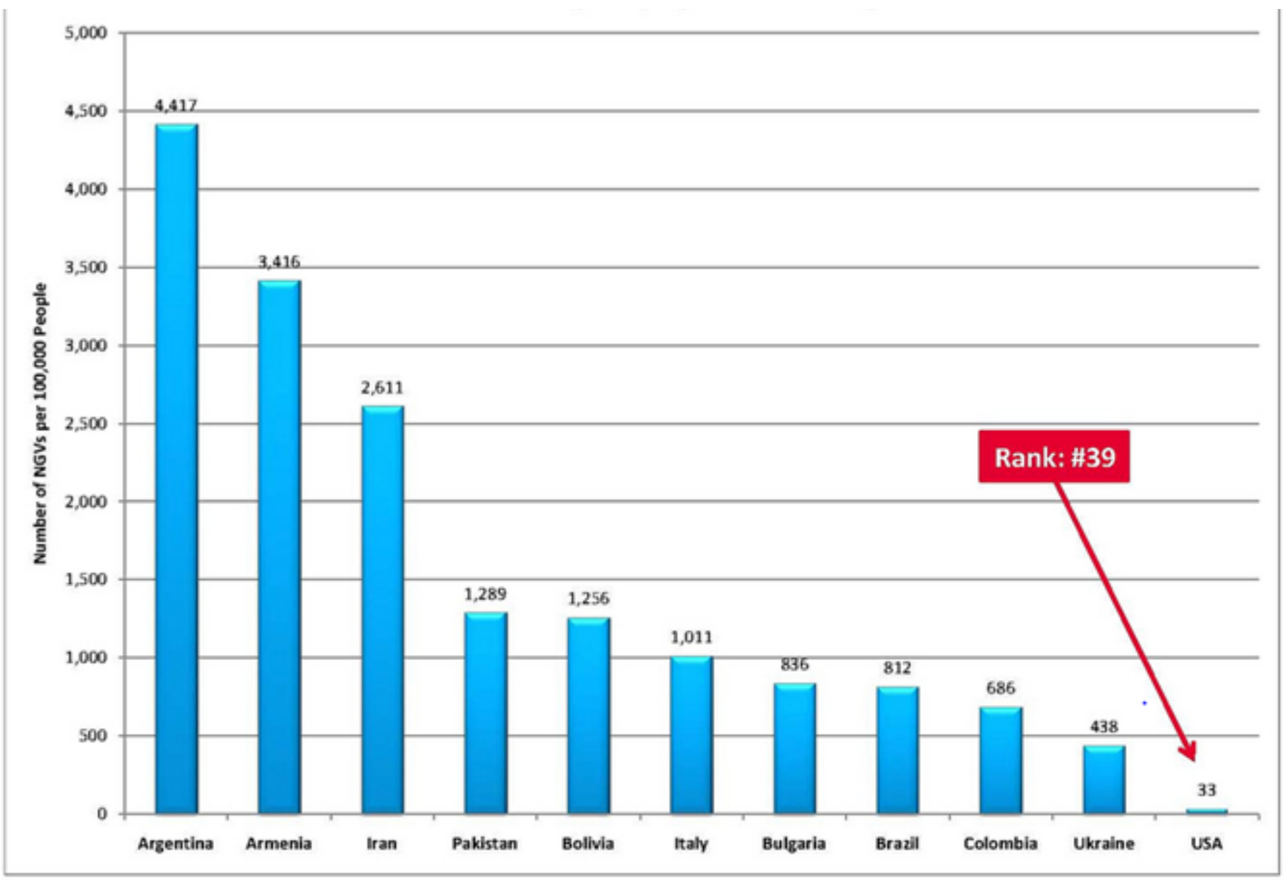


Figure 26: NGVs per Capita (Top 10 Plus U.S.) (NGV Journal)

Not only does the U.S. lag in nominal numbers of NGVs per capita (ranking 39th), but also growth rates in other countries are also far surpassing the U.S. The below figure suggests North America adoption of NGVs is nearly flat, while significant growth is shown in both South America and Asia (IHS CERA, 2010).

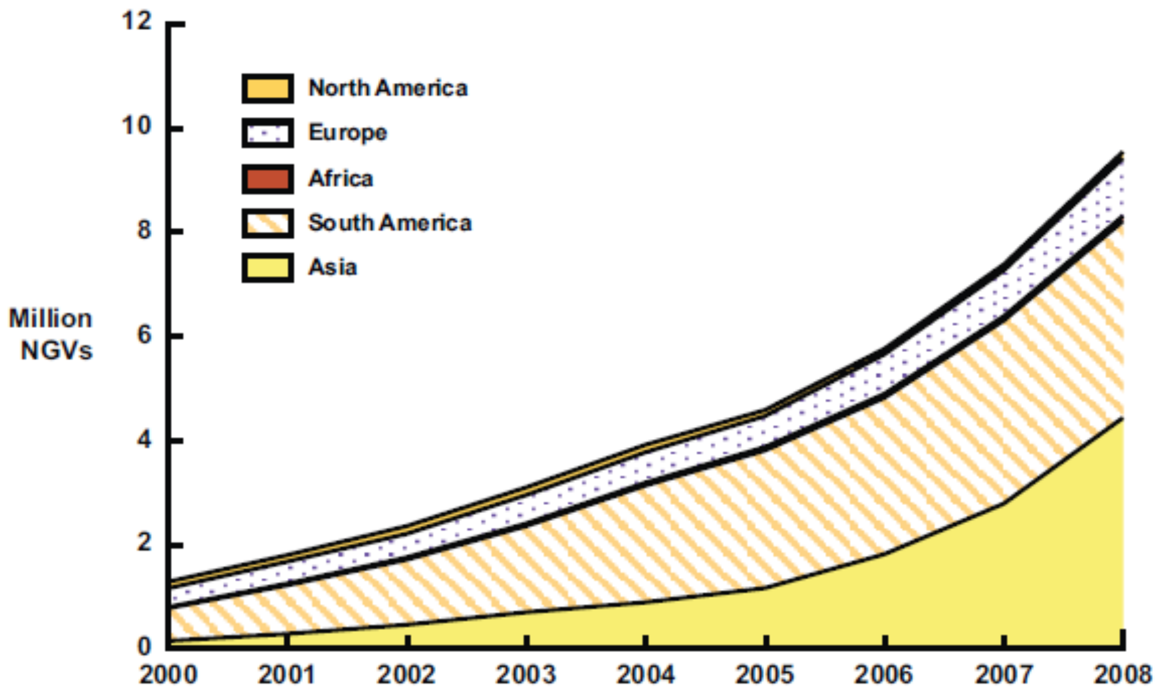


Figure 27: Global Growth in Natural Gas Vehicles (2000-2008) (IHS CERA, 2010)

Chapter 5: The Personal Test Drive

5.1 Introduction

In order to experience the challenges and benefits firsthand, I decided to test drive a natural gas vehicle and document the experience. In May of 2010, I drove a bi-fuel Chevrolet Tahoe from Austin to Boston, approximately 2,500 miles, to collect data and personalize the passenger vehicle experience. My on-road experience uncovered several challenges from a user perspective, while also confirming many of the benefits associated with natural gas vehicles. A summary of my experiences, results and recommendations are included in this section.

5.2 Planning and Preparation

Planning for the road trip included deciding on the best route from Austin to Boston that would allow for adequate CNG refueling, as well as identifying a vehicle that could be used for the on-road experiment.

5.2.1 The Route

I decided the trip would begin in Austin, where I was living as a student at The University of Texas, and conclude in Boston, Massachusetts. Boston is approximately 2,500 miles from Austin, offering a challenging route through different regions of the country with varying CNG infrastructure.

Designing a route that minimized the risk of running out of fuel required detailed planning. The planning involved mapping out the existing CNG stations within particular constraints (minimizing distance between stations, staying on interstate highways where possible, arriving on days and at times when the stations are open) and then connecting the dots to create the best route. Two online tools that were particularly helpful in locating stations were the DOE Alternative Fuels Data Center and the "CNG Prices" website (www.cngprices.com). While both websites include station-specific data, I recommend calling ahead to verify certain details, such as their hours, public access and accepted forms of payment.

Having to devise a route that snaked across the country at the mercy of a limited refueling infrastructure network was the first challenge. A traditional road trip to Boston, according to Google maps, would total 1,953 miles as shown by the route in the figure below.

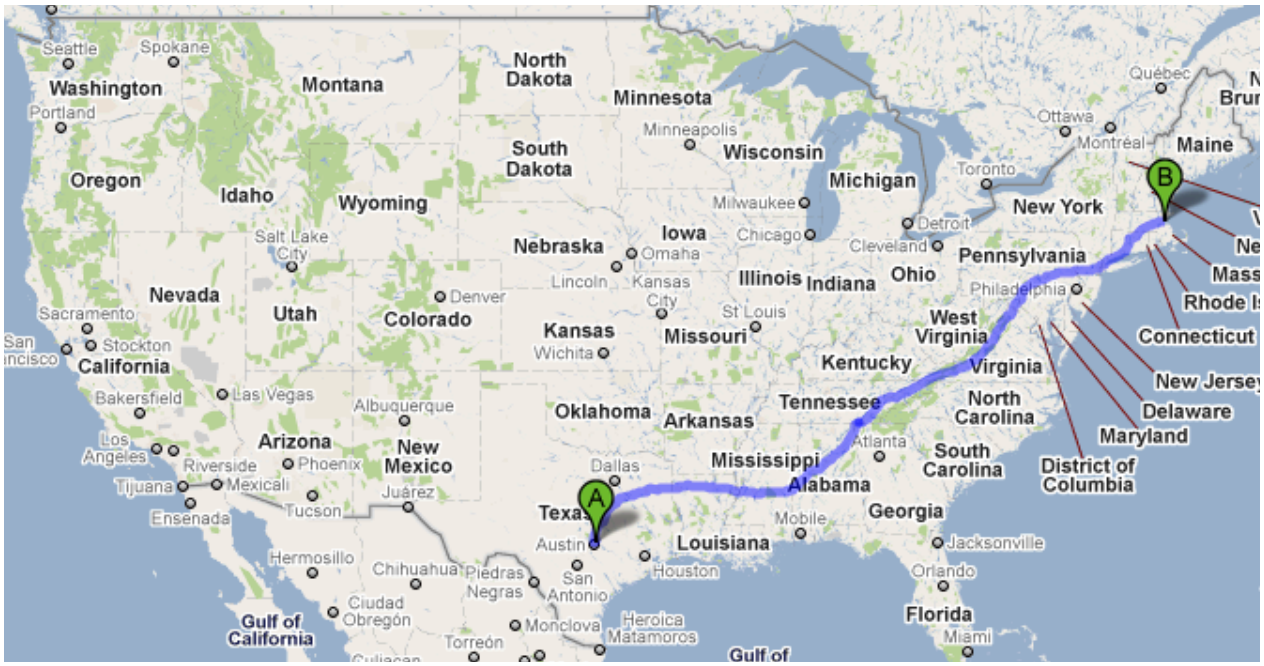


Figure 28: Shortest Route from Austin, TX to Boston, MA of 1,953 miles according to Google Maps

But keeping in mind that my route would need to be different given the need to stop for CNG, the final planned route totaled 2,473 miles, adding over 500 miles to the total trip distance. The below map shows the stations I identified for CNG refueling along the journey.

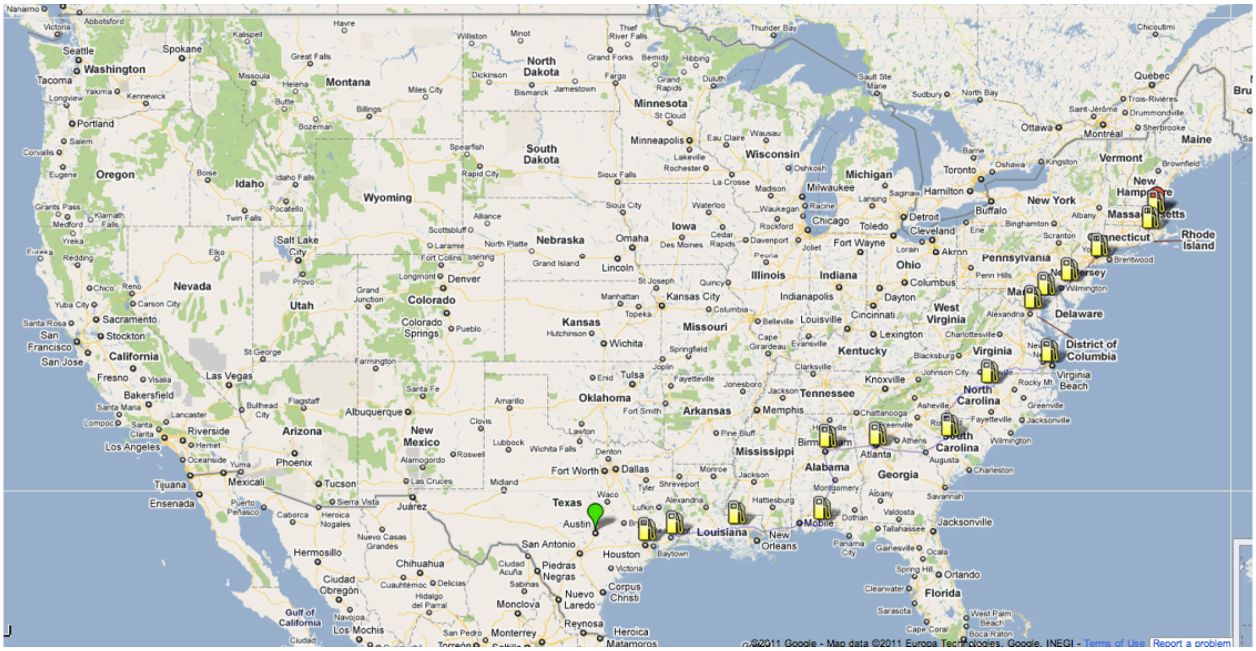


Figure 29: Route from Austin, TX to Boston, MA via CNG fueling stations, 2,473 miles

5.2.2 The Vehicle

Given the drawbacks of limited refueling infrastructure and vehicle choices, selecting the right vehicle to make the journey also presented a challenge. The Civic GX may be a good fit for certain applications, but its CNG tank can only hold 7.8 GGEs of CNG for a total range of less than 200 miles. Some of the stretches between refueling stations, such as Baton Rouge, LA to Milton, FL, however, were nearly 300 miles. A larger vehicle with room for additional tanks would be needed to successfully make the trip. Before the trip had even begun, the lack of stations had already presented a significant challenge.

During the planning phase of the trip, I learned Apache Corporation, a Houston–based oil and natural gas company, was working to convert their existing fleet vehicles (mostly light-duty pick-up trucks) to natural gas. The company had also joined the national conversation on alternative fuels, particularly CNG, and was actively looking for opportunities to educate the public on the CNG option. Apache agreed to lend me one of their vehicles, a converted 2009 Chevrolet Tahoe, for the purposes of my road trip.

The Tahoe had been newly purchased from a Chevrolet dealership in Tomball, TX, Parkway Chevrolet. Parkway also has a conversion business, Parkway CNG Conversions, where certified technicians install EPA-approved CNG conversion kits. Upon the purchase of the vehicle, Apache Corporation immediately had the vehicle converted to a bi-fuel CNG-gasoline vehicle using an IMPCO conversion kit certified for a 2009 Chevrolet Tahoe. The standard conversion includes two CNG tanks (with a 4.6 GGE CNG capacity each), which are mounted under the vehicle, giving the vehicle a total CNG tank capacity of 9.2 GGEs.

Figure 30: Apache Corporation Bi Fuel Chevrolet Tahoe

To meet the needed range between CNG refueling stations for the trip, three additional tanks were added. Two of the tanks were installed under the vehicle (see

Figure 33 below) and three were installed in the rear cargo area (see Figure 34 below), giving the Tahoe a total CNG fuel capacity of 23 GGEs.

Figure 31: Image of standard undercarriage mount of two CNG tanks.

The inclusion of the three additional tanks forced the removal of the third row of seats and underscores the amount of space the tanks can take up in a vehicle.

Figure 32: Image of three additional CNG tanks

5.2.3 Documenting the Trip

In order to document the road trip, I created a companion website I used for blogging and posting photos and videos of the planning and the trip itself. In addition, social media was utilized (Facebook, Twitter, YouTube and Flickr) to share the experiences on the road. See Appendix A-D for additional details on the companion website and social media applications.

5.2.4 The Research Team

I enlisted the help of three individuals to accompany me on the road trip: Cheryl Dalton, Chad Osko and Blake Jackson. Cheryl was my co-pilot in the Tahoe and assisted with driving, recording data and photo and video documentation. Chad and Blake followed the Tahoe in a gasoline-powered 2009 Chevrolet Avalanche to record comparative data and assist with the website and social media.

5.3 THE ON ROAD EXPERIENCE

The road trip provided an opportunity to not only document the experience of driving a natural gas vehicle but also visit businesses and individuals along the route who had experience with natural gas vehicles. Along the route, meetings and interviews were conducted with vehicle conversion technicians, natural gas producers, natural gas utilities, CNG station operators, state regulators, elected officials, small business owners, fleet operators and individuals with natural gas passenger vehicles and home fueling devices. Below is a selection of highlights from the journey.

The road trip began on a Wednesday, May 19th, 2010 from a parking lot at the University of Texas at Austin. As the trip travelled east through Texas, stops were made at a CNG vehicle conversion facility, Parkway Chevrolet, at the offices of natural gas producer Apache Corporation, and at the office of natural gas utility, CenterPoint Energy. The team also stopped twice for fuel in Texas, once in Houston and later in Beaumont.

Perhaps some of the more notable events along the trip occurred on the third day, however, while travelling through Louisiana. The refueling stops up to that point had been uneventful, and the team was becoming increasingly comfortable with using CNG refueling pumps. At a CNG station in Baton Rouge, however, things did not go as smoothly. Before turning the pump on, we connected the hose to the vehicle and went through the steps to lock the nozzle in place. Typically the nozzle is connected to the vehicle and once its locked in place with the twist of a lever, the user will hear a sound as the nozzle is opened and the gas pressure equalizes between the tank and the hose. When I locked the hose in place, and thereby opened the flow of trapped gas in the hose, the hose popped off the vehicle and wildly floundered around spraying natural gas on one of the team members. While the gas wasn't highly pressurized, the experience was terrifying. Not knowing at the time how pressurized the gas was as it shot out and onto one of the team members, I was worried he was being potentially injured. After a few seconds, we were able to grab the head of the hose as it finished venting the remaining gas in the line. Our team member, while shaken, had fortunately not been hurt and noted that the gas wasn't coming out at a high pressure. We used a service phone to call a technician who came out to the station to inspect the problem. He told us that the hose should not have popped off, and had to reset the dispenser before we were able to reconnect the hose and fill the tank.

The next notable event on the trip happened only a few miles outside of Baton Rouge. We were headed east towards the next stop, a refueling station in Milton, FL approximately 290 miles from Baton Rouge, and the longest stretch between stations on the entire journey. Along I-12, however, we hit a major traffic jam. The heavy congestion, the result of a major accident involving an overturned 18-wheeler, lasted over 12 miles and took us nearly three hours to get through, with consistent stopping and then slow acceleration for a few feet before stopping again. According to DOE, idling a vehicle significantly reduces fuel economy, and the three hours we spent travelling only 12 miles likely wasted approximately 1-2 GGEs of the CNG in our tanks we needed for the long road to Milton (U.S. Department of Energy, 2011). Nearly 40 miles outside of Milton, the fuel indicator on the Tahoe began flashing, the kit's way of notifying the driver that the fuel level is low. When the Tahoe runs out of CNG, the indicator continues to flash but also begins beeping, as it automatically switches over to gasoline. We pulled into the Milton, FL station with the indicator still flashing but no beeps – we had just barely made it.

This experience highlighted three challenges with CNG vehicles. One, while the tank capacity may be for a specific amount of fuel, users don't always get a 100 percent fill. Many factors can affect the amount of CNG that is actually dispensed at any given time (such as ambient temperature, for example, as discussed in Chapter 4). I have filled the Tahoe on several occasions (outside of this road trip) when it was completely out of CNG, and while technically five tanks have a total capacity of 23 GGEs, I've never been able to add more than 17 GGEs at a fill-up. In fact, Parkway Chevrolet shared that in their experience tanks usually only receive up to an 80 percent fill (email from Chris

Hughes on July 24, 2011). When we fueled the vehicle that morning in Baton Rouge, we added just over 10 GGEs to the tanks. The fuel gauge was showing 2 lights, meaning the tanks were between ¼ and ½ full. A full fill, or 22.5 GGEs, should have comfortably taken the Tahoe the 290 miles to Milton, even with the three-hour traffic jam. (Assuming the Tahoe was getting a modest 15 MPG, just 20 GGEs would have given the Tahoe a 300-mile range.)

This leads to the second challenge, which is the inaccuracy of the fuel gauge. Not having a more accurate read on how much fuel is left in the vehicle makes challenging situations like the Baton Rouge to Milton leg of the trip frustrating. The third challenge illustrated by this situation was the limited infrastructure's impact on long-distance travel. While I spent hours planning the trip, and knew on paper the vehicle should be able to comfortably make the 290-mile journey to Milton, the accident was something I couldn't have predicted. Perhaps this lesson is when planning a long distance CNG trip, a driver has to factor in the likelihood of unforeseen challenges and, if possible, include some extra padding in their range.

The challenges continued when we actually reached the Milton station. While we were relieved to have made it all the way there without running out of fuel, upon our arrival at about 7pm on a Friday evening, the "24-hour" station was closed. A call to the city (the police department, in fact) revealed that after 4pm on Fridays when City Hall closes, a special key card is required to activate the card reader and make payment at the station. The card reader could be obtained for a $50 deposit by visiting City Hall in person during business hours, a detail we were unaware of. Realizing we would not be able to get a card until the following Monday, it looked as if we had two options: stay in Milton for the weekend, get fuel Monday morning and continue the trip or continue the trip without refueling, run out of CNG and be forced to travel the next leg to Birmingham, AL using our gasoline reserve. Before a decision was made, we attempted to refuel anyway, even thought we didn't have a key card. Amazingly, the lack of a key card did not prevent us from turning on the pump and filling the vehicle, it did however, prevent us from being able to pay with a credit card. We refueled and noted the total charge, $19.41 for 13.96 GGEs (additional evidence that refueling doesn't always result in a full fill). Without a way to pay, I wrote a check to the City of Milton, which I enclosed in a letter explaining our situation. The City of Milton cashed the check.

Another notable stop on the trip was in Athens, GA when the team stopped to visit a family who had a NGV they used for personal use and a home refueling device installed in their garage. The family demonstrated connecting the hose and turning on the home fueling appliance, and noted that by using a home fueling device, they paid only about $1.25 a GGE. This stop was memorable because it highlighted one key advantage for NGV passenger vehicle use: an affordable and easily available home fueling device could address the current challenge presented with limited large refueling infrastructure.

Another highlight of the road trip occurred once the team made to Washington, DC. While in the nation's capitol, the team took the Tahoe to Capitol Hill. Congressman Dan Boren of Oklahoma hosted us, and arranged to have the Tahoe displayed outside of the House office buildings giving Members of Congress and their staff an opportunity to see a natural gas vehicle first hand and hear about the road trip.

The final highlight of the trip was the arrival at our final destination, Boston, MA. During the 10 day trip, the Tahoe travelled 2,500+ miles, stopped at 15 CNG stations, made seven public appearances, held 28 meetings with natural gas stakeholders, participated in three television interviews, eight print interviews and chronicled the journey on the trip's companion website, www.greenamericanroadtrip.com, which received over 15,000 visits.

5.4 Trip Impressions and Recommendations

By the most basic of standards, the trip was successful: the 2,500+-mile journey to Boston was completed in 10-days using only CNG as the fuel. And, using CNG saved nearly 24 percent on fuel costs compared with gasoline. In addition, anecdotally, the car's performance and feel (acceleration, etc.) were indistinguishable from conventional gasoline cars. However, as described above, the trip was not without its challenges. Some of the challenges were the result of the long distance nature of the trip, however, and from a passenger vehicle perspective, might not actually inhibit users who do not intend to take their NGV on a long distance road trip.

5.4.1 Refueling Process

In addition to the challenges highlighted above, there were several, smaller challenges we encountered along the way, particularly when it came to the stations. Many of the stations were difficult to locate; without GPS and an internet-enabled laptop, some would have been almost impossible to find. Some of the city-run stations were also surprisingly difficult to use. While many city-run stations claim they are open 24-hours and to the public, some are actually only "fully" open during business hours. Outside of those times, special permission is required to use their stations, as our experience at the Milton, FL station suggested.

The stations visited were either public stations operated by a private business (Clean Energy in Houston and New York City, for example), a municipal station (such as Austin, Beaumont, and Milton) or operated by a gas utility (Entergy, Virginia Gas). The privately operated stations, such as the Clean Energy stations, were commonly open 24 hours and were notably newer than some of the municipal stations. The fueling prices at Clean Energy, however, tended to be the highest of the trip ($2.13/GGE in Houston and $2.30/GGE in New York, for example, compared to a trip average of $2.00/GGE).

The team encountered a couple of issues at municipal stations, as well, which seemed to have more restrictions on access times. The requirements to use the Milton, FL station, for example, were very inconvenient. If a user is not local and simply passing through, these restrictions on a "public station" are misleading. The municipal/government run stations, however, did have some of the cheapest fuel prices at $1.39/GGE in Milton and $ 1.37/GGE in Birmingham at the Birmingham Jefferson County Transit Authority Station, for example.

Another challenge involved varying local ordinances. At a Clean Energy refueling pump in Flushing, NY near LaGuardia Airport, the team learned that there is a local ordinance requiring users to complete a CNG safety course and display a certification card in order to use a CNG refueling station. Fortunately for the team, a Clean Energy employee was onsite to service the station and offered to operate the pump on our behalf.

While the overall refueling process is somewhat similar (insert a credit card into a card reader, attach the hose, lock it in place, and turn it "on"), most gasoline nozzles across the country are similar and consistent. The refueling nozzle technology for CNG pumps, however, varied widely from station to station. Many of the stations use different equipment and, while relatively similar, have their own idiosyncrasies.

Refueling equipment needs user-friendly and safe. Pump instructions need to include when payment is made in the refueling process. This sometimes created confusion for the team, particularly if payment was made through a separate system from the dispenser. Standardized refueling infrastructure, particularly nozzles, would go a long way to making stations easier to use. Many of the stations use different equipment and while relatively similar have their own idiosyncrasies.

Furthermore, as additional CNG infrastructure is developed, station operators should aim to build stations that are open to the public, open 24 hours and able to accept standard forms of payment such as credit cards. Meeting these three would allow for a wider audience of possible users.

5.4.2 Fuel Measurement

Another challenge on the trip was measuring fuel consumption along the way. On many of the conversions, the kit includes a simple in-dash lighted display of four dots measuring the tank's fuel level in quarters, which does not offer the driver a very precise gauge. The difference between one dot and zero dots is dramatic, and in contrast to the gasoline car's analog dial that shows the needle slowly ebbing towards "E" or empty.

Measuring the amount of CNG consumed, and the amount remaining in the tank became a running joke – as in "we have 2 dots lefts" when we really had no idea how far a dot was going to get us. We were unable to accurately keep track of how many miles we traveled before we lost a dot because the numbers varied widely from dot to dot. The experience on the road from Baton Rouge, LA to Milton, FL when the Tahoe almost ran out of fuel highlighted the uncertainty a user has when trying to estimate the amount of fuel left in the tanks.

A more accurate gauge measurement on the bi-fuel converted vehicles is critical; one can't afford to guess with the current limited refueling infrastructure. In-dash fuel gauge technology (like in the Honda Civic GX) would have been far superior to the converted “dot” indicator we had on the Tahoe.

5.4.3 Fuel Economy

Another interesting observation was the Tahoe’s fuel economy. In an effort to collect comparative data, the bi-fuel Tahoe was followed by a gasoline-powered Chevrolet Avalanche (driven by other members of the research team). The vehicles had the same engine and similar weight. While not a perfect gauge, we found that the CNG-powered Tahoe earned roughly 18.95 mpg, while the Avalanche earned 18.24 mpg. Generally, the fuel economy is expected to be about the same (both are rated at 16 mpg for city driving and 21 mpg for highway driving, according to the DOE). It is possible standard variation among vehicles or ethanol blending requirements that made the Avalanche less efficient (and possibly skewing the conversion that one gallon of gasoline equals one gallon of gasoline equivalent of CNG).

Furthermore, my resulting trip MPG numbers suggest that either CNG is actually significantly more efficient than gasoline, or one GGE does not actually equal a gallon of gasoline. It has been suggested to me that ethanol-blending requirements are making gasoline less efficient and therefore skewing the conversion. Regardless, BTUs may be a more accurate way to measure the fuel.

5.5 Summary of Results

This road trip experience confirmed the benefits – the cost savings were real as were the reduced tailpipe emissions, which were tested independently before the trip by an automotive technician in Austin.

The data collected on the trip, displayed below, showed it was approximately 24 percent cheaper to fuel the CNG Tahoe than the gasoline powered Avalanche. The average per gallon price was $2.64/gallon of gasoline and $2.09 per GGE of CNG. Interestingly, this trip took place in 2010. Today's spread would have resulted in even greater fuel savings.

The trip data also uncovered a slight improvement in fuel economy for the CNG Tahoe over the gasoline Avalanche, with an average mile per gallon rate of 18.24 gallons per mile in the Gasoline Avalanche compared to 18.95 mile per gallon for the CNG Tahoe.

Based on the amount of fuel consumed in each vehicle, an estimate was also calculated for total carbon dioxide emissions, and showed a 25 percent reduction in CO2 emissions for the CNG Tahoe.

	Gasoline*	CNG**	CNG Savings (%)
Total Fuel Cost	$ 373.19	$ 282.59	24%
Avg $/Gallon	$ 2.64	$ 2.09	21%
Avg MPG	18.24	18.95	-4%
$/Mile Travelled	$ 0.14	$ 0.11	24%
CO2 Emissions (kg)* **	1250.86	934.66	25%

*The Gasoline Avalanche travelled a total of 2,576 miles, and used 141.18 gallons of gasoline for a total cost of $373.19

**The CNG Tahoe travelled a total of 2,564 miles, and used 135.26 gge of CNG for a total cost of $282.59

*** Assumes 8.86 kg of CO2 per gallon of gasoline, 6.91 kg of CO2 per gge of CNG

Table 11: Experimental Road Trip Summary Fuel and Emissions Data

5.6 CONCLUSION

The on-road experience of the experimental road trip provided a perspective I likely would not have gained by simply reading about the benefits and challenges of natural gas vehicles. The trip provided real data to support the notion of CNG's attractive pricing as well as reduced tailpipe emissions.

The challenges we encountered on the road underscored the difficulty of long distance travel in a natural gas passenger vehicle, but many of our challenging experiences may not be as much of an issue for passenger vehicle users who plan to stay near their home and use their NGV for commuting. The stop along our trip to meet the Georgian family, who had a passenger vehicle and a home fueling device, highlighted a real opportunity for the passenger vehicle market. Not only did the family avoid the inconvenience of an under-developed, national network of CNG refueling stations, by filling up each day in their garage, but they also took advantage of significant cost savings by paying for the fuel directly from their natural gas utility.

The trip uncovered obstacles to NGV use and refueling, such as quirky refueling pumps, inconvenient station hours, and imprecise fuel gauges, but none of the challenges we encountered were insurmountable. In fact, most of the challenges experienced on the road were simply annoying inconveniences as opposed to undefeatable obstacles.

Chapter 6: The Future of the U.S. Passenger NGV Market

6.1 Introduction

As noted before, there are some compelling reasons to consider natural gas vehicles an attractive option for passenger vehicles if two obstacles to greater use are addressed: inconvenience and vehicle cost. How and to what degree these two challenges are overcome will ultimately determine whether or not consumers embrace the passenger NGV option.

According to recent studies, a review of public opinion suggests passenger vehicle drivers are open to the natural gas vehicle option, but also reveals the greatest barriers for consumers are inconvenience and cost (Mayur, 2011). The inconvenience associated with refueling the vehicles and the high incremental cost of NGVs could be potentially minimized through a variety of approaches. The inconvenience could be addressed through the parallel growth of the heavy-duty and fleet vehicle market, which in turn could result in the increased build out of public refueling infrastructure, the development and increased availability of a home fueling device and/or the development of bi-fuel, and/or bi-fuel hybrid vehicles which would make a dedicated dependence on CNG infrastructure more flexible.

The high incremental cost of passenger NGVs could be reduced if costs are lowered through technological development, the benefit of economies of scale, an expanding price spread between CNG and gasoline and/or the availability of government incentives.

A review of current market trends and challenges detailed in this analysis suggests, in the absence of significant changes, particularly in price, it is unlikely NGVs will become a significant player in the passenger vehicle market.

6.2 THE NGV OPPORTUNITY

If current obstacles are overcome and NGVs for passenger vehicle use increase, there will be a resulting increase in natural gas demand. The magnitude of demand increase varies based on a variety of passenger NGV growth scenarios. Currently, there are approximately 110,000 NGVs (total for heavy-duty, fleet and light-duty and vehicles) on the road in the U.S., representing less than 1 percent of total U.S. vehicles and consuming only .1 BCFD (NGV Journal, 2010). With total U.S. demand averaging 66 BCFD in 2010, this equates to less than .16 percent of total natural gas demand (U.S. Energy Information Administration, 2011).

IHS CERA considered two different growth scenarios in the passenger NGV market. A modest scenario growing the NGV share of passenger vehicles from current levels to 10 percent of the total 237 million-passenger fleet, or nearly 23 million vehicles, would result in increased natural gas demand of 2.5 BCFD, or an increase of nearly 4 percent (IHS CERA, 2010).

At the other extreme, converting all 237 million U.S. light duty vehicles on the road today would result in an increase of 36 BCFD, or an overall increase of 58 percent. IHS CERA acknowledges converting the whole fleet is far from realistic. Even if converting the whole fleet were feasible, it would take decades to accomplish (IHS CERA, 2010).

The below figure summarizes the potential natural gas demand impacts of various sectors of the U.S. transportation market (at various levels), including heavy-duty and transit sectors, converting to natural gas.

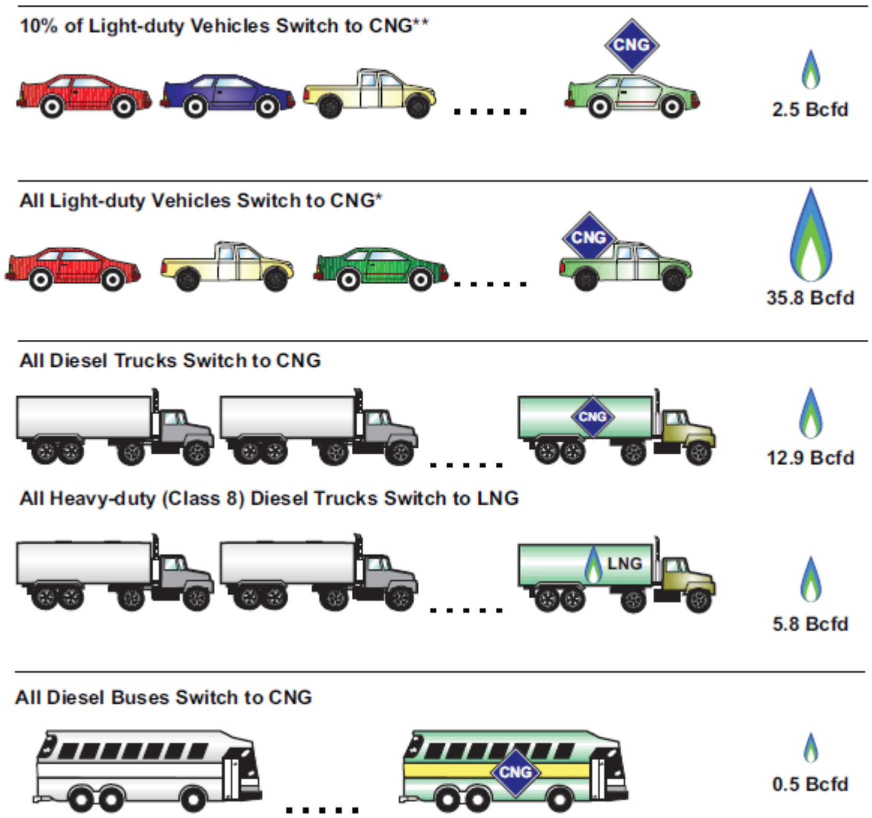


Figure 33: Potential for Increased Natural Gas Demand (IHS CERA, 2010)

With increased domestic natural gas production, EIA expects total marketed natural gas production to grow 5.8 percent in 2011 over 2010. Meanwhile, domestic demand for gas is not keeping up with production growth. EIA anticipates total natural gas demand will grow by only two percent in 2011 over 2010. If production continues to outpace demand, there may be an opportunity for expanding natural gas demand without significantly affecting natural gas prices.

6.2.1 Alternative Fueled Vehicles and Public Opinion

Perhaps one important indicator of the future viability of passenger NGVs is the public's perception. Sometimes the greatest challenge for new and different technologies is the unwillingness of consumers to embrace them. A recent study suggested passenger vehicle consumers are actually already quite comfortable with the idea of NGVs, more so than other alternative fueled vehicles. TechnoMetrica found nearly 70 percent of Americans are familiar with the NGV option, and nearly half of those would consider purchasing one (Mayur, 2011).

This perception has been aided by the new understanding of U.S. natural gas supplies and low prices. But while consumers seem open to the idea of the NGV option, another recent survey found the main concerns buyers have with alternative fueled vehicles continue to be cost and convenience. If NGVs cannot address the cost issue (incremental cost of OEM NGVs and conversion kits) and convenience (refueling infrastructure), expanded use will continue to face challenges (Dunn, 2011).

6.2.2 NGV Market Outlook and Trends

Globally, prospects for NGVs are strong with the current world total at 12.6 million vehicles expected to jump to 28.7 million by 2015 (Mayur, 2011).

Domestically, as the U.S lags the rest of the world, the short-term focus for natural gas vehicle market development is on heavy-duty and fleet vehicles, which have the lowest payback periods. The Pickens plan, for example, encourages the focused conversion of the nation's heavy-duty fleet to natural gas and infrastructure to support their refueling (The Pickens Plan, 2011).

The Pickens Plan, championed by oil and gas businessman T. Boone Pickens, is perhaps the most obvious example of the recent increased interest in natural gas vehicles. Pickens has invested over $80 million in the Pickens' Plan campaign in an effort to educate policy makers and the public to the opportunity natural gas provides the U.S. transportation sector (R. Emmett Tyrrell, 2011).

Representatives of natural gas utilities have also voiced their belief (and hope) that natural gas will play a growing role in meeting domestic transportation needs. The CEO of Southern California Gas Co., Michael Allman, recently commented that he believes natural gas will fuel more vehicles than electricity in 2020. Allman noted that the widespread use of NGVs in other parts of the world is evidence that the technology exists and can be successfully utilized in U.S. (Natural Gas Intelligence, 2011).

6.2.2.1 Trends in Heavy-Duty and Fleet Vehicles Markets

This shift to natural gas is already underway in the U.S. with many examples already evident as heavy-duty and fleet vehicles convert to natural gas. Examples include recent announcements of city bus conversions, trash truck conversions and smaller vehicle fleets to natural gas.

United Parcel Service of America, Inc. (UPS), the world's largest package delivery company, has made a commitment to adding alternative-fueled vehicles to its fleet of delivery trucks. In fact, UPS operates one of the largest private fleets of alternative fuel vehicles after beginning to convert to CNG in the 1980s. UPS recently announced the addition of 245 new CNG delivery trucks to its national fleet, bringing its CNG total to 1,100 trucks. According to a study by the National Renewable Energy Laboratory (NREL), the UPS CNG trucks reduce carbon monoxide emissions by 75 percent; nitrogen oxides by 49 percent and carbon dioxide by 7 percent lower over diesel-powered trucks (America's Natural Gas Alliance, 2011).

AT&T is another example of a company moving their fleet to CNG with the recent addition of their 2,000th CNG vehicle. Furthermore, AT&T has announced plans to add 6,000 additional CNG vehicles to their corporate fleet over the next five years (America's Natural Gas Alliance, 2011).

The City of Los Angeles, California has the nations' largest fleet of CNG buses with 2,214 CNG-powered public transit buses. The City of Lafayette, Louisiana also recently announced the purchase of six CNG-powered public transit busses (Welty, 2011).

The City of Ogden, Utah has been an example in the move by municipalities to save fuel costs and move to cleaner alternative fuel vehicles. Ogden recently added 10 CNG powered refuse trucks to their municipal fleet. The City of Seattle, Washington has also embraced CNG for refuse trucks through a contract with Waste Management (WMI) whereby WMI purchased 106 new CNG-fueled refuse trucks (America's Natural Gas Alliance, 2011).

Seattle has also seen the use of NGVs in a fleet of taxis operated by the Seattle-Tacoma International Taxicab Association, which operates 166 CNG-powered Ford Crown Victoria cabs. Washington, DC's parking enforcement division has also embraced CNG vehicles with the majority being CNG powered Honda Civics (America's Natural Gas Alliance, 2011).

6.2.2.2 Indirect Benefit for the Passenger Market

The increased interest in heavy-duty and fleet vehicles, while not directly linked to the growth of a passenger vehicle market, could have indirect benefits. The increased overall interest could lead to innovation and even economies of scale in NGV technology, both for vehicles and refueling infrastructure. The build-out of infrastructure to support new heavy-duty and fleet NGVs could also be available to a growing passenger vehicle market as well, assuming the new infrastructure is open to the public.

In a recent and growing trend, the natural gas producer community has also begun to participate in the development of natural gas refueling infrastructure. The producer community sees the supplies and likely future low price environment as an opportunity to expand demand for their product (Apache Corporation, 2011). Many natural gas producers are working to convert their fleets to natural gas and have built refueling infrastructure to support the refueling needs of the fleet, such as Apache Corporation and Southwestern Energy. EnCana Corporation, a Canadian natural gas producer, has even incorporated a subsidiary to address natural gas refueling infrastructure. In 2010, EnCana Natural Gas Inc. was established in the U.S. to operate natural gas fueling stations, and opened their first north of Denver, CO in 2011 (BuinessWeek, 2011).

Chesapeake Energy Corporation (Chesapeake) recently announced the creation of Chesapeake Natural Gas Ventures, a one billion dollar fund to accelerate the use of natural gas as a transportation fuel. In a company press release on the announcement, Chesapeake explained their efforts will assist in the build out of “enough publicly accessible compressed natural gas (CNG) and liquefied natural gas (LNG) fueling stations to reach a tipping point where original equipment manufacturers (OEMs) of all vehicular classes will have sufficient confidence to increase their production of CNG and LNG vehicles and provide American businesses and consumers access to vehicles that run on a cleaner fuel…” (Chesapeake Energy Corporation, 2011).

6.2.2.3 Trends in the Passenger NGV Market

Evidence automakers see a possible future in the passenger vehicle market is seen in recent announcements from both Honda Motor Company and General Motors. Honda recently announced that beginning in Fall 2011, they would, for the first time, offer the Honda Civic GX in all 50 states. The auto manufacturer’s decision to offer the vehicle more widely reflected the increased interest they see in the U.S. (Weekly Driver News Source, 2011). After originally introducing the Honda Civic GX in 1998, the vehicle was previously only available in four states. A reevaluation of the marketing strategy resulted in a 2005 decision to offer the vehicle to individuals as opposed to only targeting government and commercial fleets as done previously.

General Motors also recently announced plans to partner with Westport Innovations to develop a natural gas engine for passenger vehicles (Westport Innovations Inc., 2011). In a press release issued by Westport, Ian Scott, President of Westport's Light-Duty Division noted, "we are excited to work with GM and invest in advanced natural gas technology for the automotive market. This technology offers the promises of a cleaner, lower cost fuel and reduced carbon footprint, while advancing the use of domestic energy."

As noted in Chapter 4, there are several passenger OEM vehicle options available outside of the U.S., even by U.S. auto manufacturers such as Ford. The recent merger of Fiat and Chrysler also provides an opportunity for new NGV options in the U.S. passenger vehicle market as Fiat offers several NGV passenger options in Europe. Fiat and Chrysler Group, LLC CEO, Sergio Marchionne, recently shared intentions to evaluate the U.S. market for expanded sales of passenger NGVs. Marchionne said, "natural gas engines offer a better way to cut emissions because they're cheaper than competing technologies." He highlighted Fiats expertise in the field by adding, "Fiat's technological leadership in compressed natural gas in Europe is a key asset for the U.S. natural gas-vehicle market," (Higgins, 2010).

Manufacturers are also looking into offering OEM flex-fuel NGV vehicles, or vehicles capable of running on multiple fuels, especially given the preference for bi-fuel conversions in passenger vehicle conversions. HK Motors, a California-based subsidiary of Hybrid Kinetic Group Ltd. of Hong Kong, recently announced plans to produce a bi-fuel hybrid electric vehicle in the United States, but project financing remains to be finalized. The vehicles would be capable of running on CNG or gasoline and include an electric battery (HK Motors).

6.3 Addressing Market Development Challenges

As previously mentioned in both the discussion on NGV drawbacks and the survey results of consumer preferences, the continued obstacles for greater NGV use in the passenger market are convenience and cost. The convenience aspect of refueling creates a significant obstacle, and while expanded infrastructure to support a growing heavy-duty and fleet presence discussed above could alleviate convenience concerns, it may not be enough. In addition, the high incremental cost of NGVs must be addressed.

6.3.1 The Infrastructure Challenge

The inconvenience associated with NGVs is based on the limited refueling infrastructure, evidenced in the road trip. But the current limitations could be minimized in three ways: the parallel growth of the heavy-duty and fleet vehicle market which in turn could result in the increased build out of public refueling, the development and increased availability of a home fueling device and/or the development of bi-fuel, and/or bi-fuel hybrid vehicles which would make a dedicated dependence on CNG infrastructure more flexible.

6.3.1.1 Public Refueling Infrastructure

The possibility for growth in the heavy-duty and fleet markets could indirectly benefit the passenger market was discussed above. As new infrastructure is built to support increased NGV traffic, the stations built must include public access for a wider benefit. Energy Policy noted that during the transition from an initial market (with limited infrastructure) to a more mature market, the goal should be to increase refueling stations to a minimum of 10–20 percent of conventional gasoline stations (Yeh, 2007). The studies referenced in the Energy Policy article noted at these levels, consumers no longer view the availability of refueling stations as a major obstacle (Yeh, 2007). Given current gasoline stations number over 160,000 this would require 16,000 to 32,000 natural gas refueling stations, 16 to 32 times more than the U.S. has at present.

One of the obstacles to greater development of natural gas refueling infrastructure is the relative high cost of the equipment and stations. A report from the DOE estimates costs of CNG refueling infrastructure between $400,000 and $1,700,000 per station depending on the size and capacity (U.S. Department of Energy, 2010) (Whyatt, 2010).

The question of who may actually build additional infrastructure also remains unclear. While one may assume those with a vested interest in selling more natural gas would be likely candidates to invest in the refueling infrastructure, such as existing retail fuel providers, natural gas producers and natural gas utilities, for various reasons, these groups may stay on the sidelines.

The majority of existing infrastructure is owned by municipalities or fueling companies, such as Clean Energy Fuels Corporation, the largest provider of natural gas fuel for transportation in North America (Clean Energy Fuels, 2011). Existing refueling infrastructure, such as gasoline stations, could be good options for CNG pumps given they already have land and traffic for refueling purposes. To date, however, retail stations have yet to embrace the addition of CNG pumps. There are exceptions, such as stations in Utah and Oklahoma. And recently Valero Energy Corporation (Valero), a large refinery and retail fuel provider, announced plans to begin including CNG pumps at new stations (Vaughan, 2011). In addition to high infrastructure costs, existing retail fuel providers may be reluctant to sell a product cheaper than their traditional products, like gasoline and diesel in the case of Valero.

While certain producers of natural gas, such as EnCana and Chesapeake, have found creative ways to fund investments in refueling infrastructure, existing tax code restrictions complicate direct investment by independent producers in retail refueling operations. By IRS tax code definition, an independent producer is restricted from having more than $5 million in annual retail sales (TaxAlmanac). In 2011, Congressman Bill Cassidy (R-LA) introduced the "Job Creation and Energy Security Act of 2011," in the U.S. House of Representatives to exempt CNG sales from the retail cap for independent producers, but so far the cap remains a significant obstacle for direct investment by independent producers in retail refueling infrastructure (NGV Global News, 2011).

Another likely participant could be natural gas utilities, but as regulated entities, which must get approval for large investments that will be recovered through the rate base, significant utility participation seems unlikely. A handful of utilities have been able to successfully develop infrastructure such as Questar Gas in Utah and AGL in Georgia. Questar Gas owns and operates 25 CNG refueling stations and AGL recently announced plans to build out refueling infrastructure through a public-private partnership (Green Building Chronicle, 2011).

Perhaps one of the most important components of expanded natural gas refueling infrastructure and a successful conversion of the U.S. passenger fleet, is that the market includes a diverse mix of refueling participants to encourage competitive retail pricing. In cities without multiple options, prices tend to be higher because a lack of competition.

6.3.1.2 Home Refueling Infrastructure

Certainly the addition of public refueling infrastructure will assist in reducing the inconvenience of refueling NGVs, but there are other ways to address the refueling challenge as well, specifically with the increased use of home refueling devices. Home refueling devices were discussed in Chapter 4, but the exciting opportunity they provide cannot be understated in addressing the current lack of public refueling infrastructure.

In a poll conducted by MSNBC, participants were asked, "Would you be interested in buying a natural gas car if you could fill up at home?" 77 percent of respondents said, "Yes, the benefits outweigh the cost of the device", while 13 percent said, "No, it doesn't sound reliable", and 9 percent "Couldn't decide" (Pirraglia, 2003).

There are currently 65 million residential natural gas customers in the U.S. While the residential sector primarily uses natural gas for space heating, water heating and to power appliances, the opportunity to install an additional appliance for home vehicle refueling seems like a natural fit and the residential customers would also pay low utility rate prices (U.S. Energy Information Administration, 2010).

6.3.2 The Vehicle Challenge

The high incremental cost of passenger NGVs could be reduced through a variety of ways including a reduced incremental cost through technological development, the benefit of economies of scale, and/or the availability of government incentives.

6.3.2.1 Current NGV Economics & Payback Periods

Since the environmental benefits and energy security benefits of utilizing CNG are not accounted for in the cost (or reflected in a higher cost for gasoline), the real question drivers might ask themselves is, "will I be able to recover the incremental cost through fuel savings over the life of the vehicle?" And furthermore, if not, "am I willing to pay a premium for the intrinsic benefits the market ignores?" Payback, or the amount of time it takes a consumer to recover the upfront incremental cost, will vary depending on the incremental cost, fuel cost differential and miles travelled.

Because the economics can more easily be realized on high-mileage, low-fuel-economy vehicles, the focus has been on the heavy-duty and fleet vehicles discussed previously. The more miles a vehicle is driven per year and the less efficient that vehicle is, the more money can be saved on fuel costs by using CNG instead gasoline.

Studies suggest that most consumers want a very short payback period, less than three years (Yeh, 2007). IHS CERA contends, "The "acceptable" payback period is based on empirical studies of the implied discount rates associated with consumer decisions regarding energy efficiency investments, which show that such discount rates are typically in the 20 to 30 percent range", (IHS CERA, 2010).

Further supporting the suggestion that consumers prefer a three-year or less payback period is evidence from foreign countries with successful NGV markets, which suggest payback is a critical component in a viable market. In the countries evaluated, the average payback period for light-duty vehicles was lower than three years, and was largely the result of government policies, which reduced NGV incremental costs. The Figure below highlights the high payback periods in the U.S. relative to other countries.

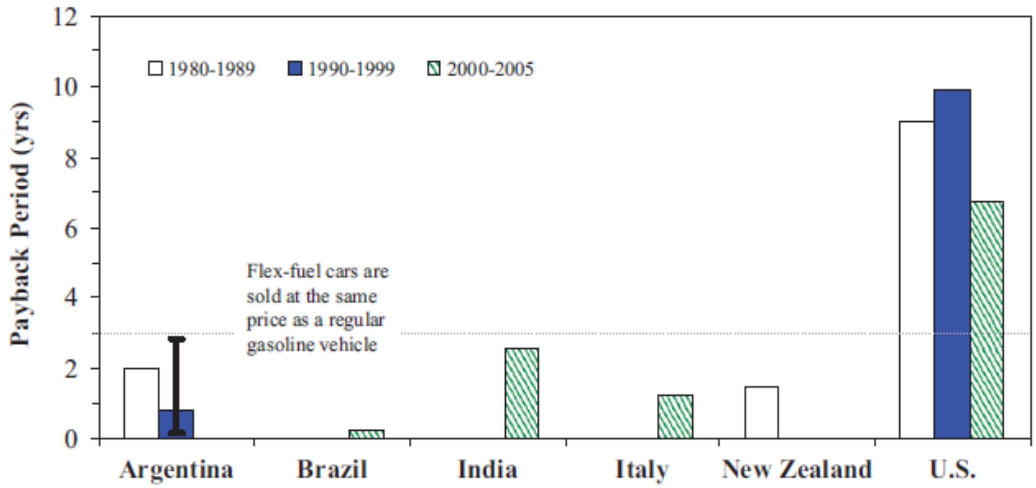


Figure 34: Payback Periods in Various Cities (Yeh, 2007)

In the absence of tax credits can passenger vehicles reach an acceptable payback period? While the vehicles certainly enjoy fuel cost savings over the life of the vehicle, passengers simply don't drive enough miles to recover the upfront cost in a reasonable amount of time. As displayed below, the average American drives 10,500 miles per year equating to payback period of 27 years for the Honda Civic GX and 19 years for a bi-fuel converted Chevrolet Tahoe. Perhaps one important takeaway from this chart is that there are differences within the passenger vehicle market. A relatively fuel-inefficient SUV, like a Chevrolet Tahoe, might actually make sense in certain scenarios (such as greater annual miles driven and a higher gasoline-CNG price spread) for the passenger market. A small Honda Civic, is by its efficient nature, not going to recover as much in fuel savings because it simply doesn't use as much fuel.

	Incremental Cost	City/Hwy Combined MPG	Annual CNG Fuel Savings	Payback in Years
Honda Civic GX (Dedicated)	$ 6,800	28	521.25	**27**
Chevrolet Tahoe, Converted (Bi-Fuel)	$ 10,000	16	912.19	**19**

Assumptions
Annual annual miles traveled of 10,500
CNG price of $2.00/gge; gasoline price of $3.39/gallon (Average prices for first half of 2011)
Similar maintenance costs
Annual Discount rate of 6%

Table 12: Payback for Natural Gas Passenger Vehicle

6.3.2.2 Lowering Incremental Cost

It has been suggested the in order to gain wider acceptance, passenger NGVs need to reach an incremental cost of $1,800 along with a $1.5/GGE fuel price spread in order to reach the three-year payback period (assuming 30 MPG and 12,000 miles/year) (Massachusetts Institute of Technology, 2010).

Of course, one could also argue that as demand for passenger NGVs increases and production lines are expanded, costs will naturally come down as a result of economies of scale, but there are additional ways to possibly lower the incremental cost and thereby shrink the payback period.

Many blame high aftermarket conversion kit costs on the EPA certification procedures required to prove the vehicle post-conversion still meets environmental standards. As an example, the $10,000 average price tag for passenger vehicle conversions in the U.S. is only $2,500 per vehicle in Singapore (Massachusetts Institute of Technology, 2010).

Vehicle conversions can potentially violate the Clean Air Act (CAA), so all new vehicles and conversion kits must pass rigorous tests to confirm the vehicle will meet CAA emission standards. Prior to 2011, NGVAmerica estimated total costs could be as much as $200,000 for the design, manufacturing and certification required for each engine family. In 2011 E.P.A revised the rules for vehicle conversion kits and expect conversion kit certification costs to be reduced as a result (Yacobucci, 2011).

Another possible approach, mentioned earlier, is the trend to make the vehicles less expensive by simply reducing the tank size and offering CNG as an option in a flex-fuel vehicle. In other parts of the world, bi-fuel options are already available. Some engines used in bi-fuel vehicles could also run on ethanol blends like E85, making these vehicles multi-fuel vehicles.

By creating OEM vehicles that are capable of running on various fuels the consumer is empowered to make fueling decisions on a real-time basis depending on which fuel is cheaper. Furthermore, by designing vehicles capable of running on various fuels, the needed size of the CNG cylinder (the most expensive vehicle component) can be smaller resulting in direct cost savings.

The bi-fuel vehicle option offers an opportunity to address both the cost and convenience concerns. The flex-fuel option or a bi-fuel vehicle would limit the need for natural gas refueling infrastructure through the vehicle design itself. By encouraging the development of additional flex-fuel vehicles, the inconvenience of a lacking public infrastructure is tempered by the flexibility drivers have to switch to another fuel when needed, such as gasoline.

Borrowing a page from the Chevrolet Volt, one way to introduce more expensive technology is by coupling it with traditional, cheaper gasoline storage (General Motors, 2011). The model for passenger vehicle use could be similar to the Chevrolet Volt model, whereby passenger vehicle use the alternative fuel (like the battery in the Volt), for daily commuting and use the backup gasoline tank for longer distance travel. The introduction of flex-fuel natural gas vehicles coupled with wider availability of home fueling devices would make this model possible.

Recent technological developments have allowed the development of smart devices, or devices that are capable of adjusting based on certain conditions. The smart meter, for example, can make adjustments to electricity use so that use can be customized to take advantage of lower electric rates (such as running the dishwasher at night during non peak hours). Similar technology is being developed for vehicles, and the bi-fuel or multi-fuel option will allow cars to be "smarter" and make decisions on fuel based on price and performance. The Fiat Siena 1.4 Tetrafuel, for example, currently available in Brazil, can run on multiple fuels and according to the International Association for Natural Gas Vehicles, "can run on CNG or on any blend of gasoline and ethanol (anywhere from pure gasoline to pure ethanol). The default fuel is natural gas, but the computer automatically senses when a different fuel would be more economical (e.g. hill requiring extra torque or acceleration). It automatically switches back to CNG when the computer determines that it once again is the appropriate fuel. It will also switch to gasoline/ethanol when the natural gas pressure drops below 150 psi" (CNGNOW, 2011). Air quality standards are not as strict in Brazil, however, so implementation of similar technologies in the U.S. would need to meet E.P.A. emission standards.

Lastly, another way the payback period shrinks is if the price spread between CNG and gasoline were to further expand. In addition to the possibility of an expanding natural gas-oil multiple as discussed in Chapter 3, the incorporation of externalities, such as carbon dioxide emissions, into existing fuel prices would increase the spread between CO2-laden gasoline relative to CNG. MIT explored a carbon policy scenario whereby a price for carbon was factored into retail prices of various transportation fuels and projected that the resulting price spread could result in a 20 percent penetration of CNG vehicles into the private fleet by 2040 to 2050 (Massachusetts Institute of Technology, 2010).

6.4 Government Incentives

Given the challenges preventing greater adoption of NGVs, governments at the federal and state level in the U.S. have employed various policy tools to encourage their increased use.

6.4.1 Existing Incentives

6.4.1.1 Federal Incentives

Currently the federal government has incentive programs in place to encourage expanded use of NGVs. Many of these programs target alternative fuel vehicles and natural gas qualifies. The main federal tax credits include:

Income Tax Credits of Alternative Fuel Infrastructure

This incentive offers a tax credit equal to 30 percent of the cost of natural gas refueling equipment, up to $30,000 in the case of large stations and $1,000 for home refueling appliances. The American Recovery and Reinvestment Act of 2009 increased the value of the credit for property placed in service during 2009 and 2010. The credit value for these years is $50,000 or 50 percent of the cost (whichever is smaller) for business property and $2,000 or 50 percent of the cost (whichever is smaller) for a home refueling appliances (Alternative Fuels Data Center, 2011).

Excise Tax Credit to the Seller of CNG or LNG

The federal government offers an excise tax credit of 50-cent per GGE of CNG or liquid gallon of LNG when sold for use as a motor vehicle fuel. The credit went into effect October 1, 2006 and expires on December 31, 2011 (Alternative Fuels Data Center, 2011).

Federal Grant Programs

There are also federal grant programs, many of which target local governments or large fleets in areas of non-attainment. The Congestion Mitigation and Air Quality Improvement Program (CMAQ) is a competitive funding program for projects in non-attainment areas. Funding levels for this program annually exceed $1 billion, and typically 5 percent goes towards alternative fuel projects (Alternative Fuels Data Center, 2011).

Another grant provides support for the various Clean Cities coalitions. The Department of Energy's State Energy Program (SEP) Special Projects expands the use of proven alternative fuel vehicles in a number of key applications, such as school buses, transit buses, airport vehicles, taxis and delivery fleets. States apply for these grants and use the grants to support local alternative fuel vehicle and infrastructure initiatives. There are also two EPA grant programs that target heavy-duty diesel vehicles in an effort to modernize the fleet (Alternative Fuels Data Center, 2011).

6.4.1.2 State Incentives

DOE maintains an updated list of state and local incentives across the United States. For a complete list visit the DOE Alternative Fuels Data Center. As an example of some of the incentives that can be offered at the state level, below is a summary of incentives in Texas. While Texas does not currently offer any tax incentives, some states, such as Oklahoma and Louisiana, offer state income tax credits.

Texas Grant Programs

To encourage fleets to increase their use of heavy-duty NGVs, the Texas General Land Office (GLO) has an NGV Initiative Grant Program available for public-sector entities in certain Texas counties. Private fleets are also eligible if they operate under contract for government work or do other government business. The program is funded with a Texas Emissions Reduction Plan (TERP) grant through the Texas Commission on Environmental Quality (TCEQ). There is also TERP funding available for conversion of diesel fleet vehicles, including public school bus fleets, and a program to replace taxis with low emission vehicles like NGVs (Alternative Fuels Data Center, 2011). In addition, during the 2011 Legislative Session, the Texas Legislature passed SB 20. The legislation, which becomes effective on September 1, 2011, will encourage the development of the Texas Clean Transportation Triangle, a plan to connect the major highways between Texas' most populated cities of Houston, Dallas/Ft. Worth and San Antonio with a sustainable network of natural gas refueling infrastructure and vehicles. SB 20 created a natural gas vehicle grant program for medium and heavy-duty vehicles (over 8,500 pounds) as well as a grant program for natural gas refueling infrastructure, also funded from the TERP program (Texas Legislature Online, 2011).

6.4.2 Effectiveness of Government Incentives

While there are many incentives currently in place at the federal and state level to encourage increased use of natural gas vehicles, debate remains over the cost-effectiveness and influence of incentives.

The National Conference of State Legislatures (NCSL) has found that in general, state alternative fuel vehicle incentives have not stimulated widespread conversion to alternative fuels. NCSL notes, "this disappointing outcome is due partly to the design of the incentives themselves, partly to the early stage of technological development of some alternative fuel vehicle technologies, and partly to the fact that alternative fuels are competing against inexpensive and well-entrenched conventional fuels" (Brown & Breckenridge, 2001).

However, there are a few markets which been more successful than others in incorporating alternative fuels into their vehicle fleets. The difference between success and the status quo seems to be the type and design of the incentive programs (Brown & Breckenridge, 2001).

In the Villanova Environmental Law Journal, Heather Munoz notes, “the current tax code uses policy-driven tax incentive provisions to induce taxpayers to alter their individual behavior to conform to Congress’ preferences, based on political or social reasons.” The effectiveness of these policies has been the source of much debate and discussion (Munoz, 2004). An important finding from Munoz suggests that motivations to purchase alternative-fuel vehicles have been found to be more closely linked to economic and energy security reasons, as opposed to environmental (Munoz, 2004).

Many argue it will depend on the specific tax incentive as to whether or not it will actually have the desired outcome, such as if it is a one-time event or continuing subsidy. Research shows that taxpayers may be more comfortable with a one-time credit because it eliminates the uncertainty of whether or not they can depend on the incentive in future years. Further, Munoz suggests tax incentives aimed at changing energy use behavior may be more effective on individuals as opposed to corporations saying, “a credit to consumers increases the demand for the tax favored product” (Munoz, 2004).

The success of one-time incentives was apparent in the recent federal CARS (Car Allowance Rebate System) program, also known as “cash for clunkers”. Villanova reports that automakers consider one-time tax credits a useful tool for encouraging consumer behavior, because the overall price of a vehicle is the most important factor for consumers purchasing a vehicle. Manufacture rebates have proven to be an effective marketing tool used for car manufacturers and similar logic suggests cash rebates (in the form of tax credits) can also be effective. In 2002, for example, GM lead the U.S.

industry in incentives, allowing it to increase profits and market share even as it reduced prices (Munoz, 2004).

The success of the CARS program underscores the effectiveness of one-time incentives. The Transportation Department reported the program resulted in nearly 700,000 new auto sales with rebates for returned vehicles totaling $2.877 billion. Originally, the program was allocated $1 billion for a three-month period in 2009, but by the end of the first week with the money almost gone, the Senate authorized an additional $2 billion (Wheels, 2009).

6.5 THE OUTLOOK FOR ADDITIONAL GOVERNMENT INCENTIVES

The benefits and policy goals of increased use of natural gas vehicles include environmental benefits, national security benefits and domestic economic development. Costs, however, continue to prevent consumers from making the choice to purchase NGVs instead of traditional vehicles. Properly structured government incentives, however, can encourage the adoption of NGVs. A review of successful alternative fuel incentive program reveals key components to successful programs, which can be used to evaluate a current proposal to encourage expanded use of natural gas vehicles, the NAT GAS Act.

Perhaps one of the more successful NGV incentives was the federal natural gas vehicle tax credit program, which expired December 31, 2010. Under the program, NGV drivers were able to take advantage of a federal tax credit for dedicated NGVs, an incentive that helped bring down the initial upfront cost. Since the expiration, supporters of the incentive have pointed to the high payback periods discussed above as a reason to reinstitute the credit. In response to calls to revive the credit, the NAT GAS Act was introduced in Congress to reinstate the credit and even expand it to include bi-fuel vehicles. Debate exists, however, as to whether or not the government should offer financial incentives to encourage users to select one fuel over another.

6.5.1 Suggested Components of Incentive Programs

Learning from the mistakes and successes of incentive programs across the country may allow supporters of NGV incentives to make the case for the most-effective forms and uses of government resources. Two studies evaluated the components of effective incentive programs: the NCSL looked at state programs and Emmistar completed a report for NGVAmerica to evaluate effective incentives. The lessons learned could be used to compose general recommendations for effective incentive programs that could be used at the federal and state level. Based on the findings of these studies, key components of successful programs include large grant or incentive dollar awards, programs that favor grants, predictable funding opportunities, reasonable program turnaround, outreach and education, and minimal administrative hurdles (Emisstar, 2009) (Brown & Breckenridge, 2001). What follows is a discussion of the needed characteristics of an effective incentive program, which could encourage the expanded use of natural gas vehicles.

Incentives need to be large enough to significantly reduce payback periods.

Incentives need to be big enough to offset enough of the incremental cost to bring the payback period into an acceptable range for consumers. Small incentives can be actually be an inefficient use of government resources unless packaged with large incentives. Some smaller incentives, such as modest fuel price discounts and sales tax exemptions do not appear to offer much support for alternative fuels by themselves (Brown & Breckenridge, 2001).

Grant based programs can be more effective

NCSL concluded that the most effective incentives are often grant-based. After a survey of the most commonly used incentive types and the most successful, NCSL found that grants and rebates have the potential to be the most successful, particularly over tax-based incentives such as tax credits. While the values may ultimately amount to the same savings, consumers prefer the simplicity of the rebate and the immediate impact, as opposed to having to wait until taxes are filed to receive the financial benefit. Furthermore, municipal governments and other non-taxable organizations (who often are early adopters of alternative fueled vehicles) cannot take advantage of tax credits (Brown & Breckenridge, 2001).

Program should include predictable funding opportunities

Consumers and businesses prefer to make investment decision in predictable environments. This is particularly important for fleet operators needing to plan budgets and purchasing decisions in disciplined budgeting cycles, but can also apply to grants that may target passenger vehicle consumers (Emisstar, 2009).

Program should be executed and money dispersed quickly

It is also important for decisions to be made on selection for grant awards and for disbursements to be made quickly. Long lag times can hurt businesses looking to make investment decisions as they wait for responses on rewards. For similar reasons, consumers prefer grant programs or immediate tax credit programs as opposed to reimbursement programs. Some purchasers may not be able to cover the incremental costs upfront and forego participating if the program is structured as a reimbursement program (Brown & Breckenridge, 2001).

Program opportunity needs to be relayed to target audiences

Equally important is the education of potential consumers to existing opportunities. Government programs need to allocate reasonable resources to outreach and education to ensure that potential applicants are aware of opportunities. Furthermore, potential program participants need to be able to receive prompt answers to questions and clarifications regarding program details and clarifications. In a study commissioned for NGVAmerica, researchers found that administrative overhead for program management can range from 1.5 percent to 15 percent of the program funding (Emisstar, 2009).

Programs should seek to reduce administrative hurdles

After reviewing many programs, the NGVAmerica study found that simplifying and streamlining program applications and implementation create higher utilization (Emisstar, 2009). The challenge for program administrators is to balance program needs and requirements with burden of applying and participating. The NCSL also found that programs need to be easy to administer, citing the California South Coast Air Quality Management District incentive, which is administered through auto manufacturers who receive the credit and pass on the savings directly to the consumer. The manufacturer immediately reimburses the dealer and then applies for reimbursement from the Air Quality Management District (Brown & Breckenridge, 2001).

These recommendations represent an approach to implementing incentive programs that could be applied at the state and federal level. When structuring incentives, it is important to note that consumer behavior is most influenced by prices. Alternative fuel vehicles, including natural gas vehicles, cannot compete with traditional vehicles without significant incentives that bring their costs down. Without compelling financial reasons, incentives alone will not lead to conversion.

The lower fuel economy and high annual mileage of heavy-duty fleet vehicles make them a good fit for targeted incentive programs because they can realize payback quicker than light-duty passenger vehicles like the Honda Civic GX. Incentive programs that aim to encourage expanded use of NGVs should also consider the additional outlined recommendations including programs that favor grants, predictable funding opportunities, reasonable program turnaround, outreach and education and minimal administrative hurdles.

6.5.2 Proposed Incentive Program: The NAT GAS Act

Based on the above recommendations, there may be an opportunity for the U.S. government to develop an incentive program to further encourage the use of NGVs. A comprehensive plan has been introduced in the U.S. Congress, the NAT GAS Act, but the prospects for bill passage remain unclear.

6.5.2.1 NAT GAS Act Background

In response to increased calls for greater utilization of natural gas vehicles in the U.S., and a raised public profile of the vehicles' promise (thanks in part to the media campaign of the Pickens Plan), legislation was introduced in the 111th and 112th Congresses to encourage a shift to natural gas vehicles. The legislation, the New Alternative Transportation to Give Americans Solutions Act (commonly referred to by its acronym, the NAT GAS Act) provides incentives for vehicles and infrastructure to support greater utilization of natural gas vehicles.

Oil and gas businessman, T. Boone Pickens, unveiled the Pickens Plan in 2008 as an energy plan that would increase wind electricity generation, upgrade and secure the transmission grid to carry renewable energy and replace foreign oil with domestic natural gas in heavy trucks. He travelled across the country for months promoting the plan, and building public support for the idea, referring to his supporters as the "Pickens Army" (The Pickens Plan, 2011). The plan's natural gas vehicle component was the predecessor to what eventually became the NAT GAS Act, establishing incentives to convert the a portion of the heavy-duty fleet and build out the needed supporting refueling infrastructure (Wellkamp & Weiss, 2010).

H.R. 1835, the New Alternative Transportation to Give Americans Solutions Act of 2009, was introduced in April of 2009 by Congressman Dan Boren (D-OK) and had 146 cosponsors. By July 2009 a Senate companion, S. 1408, had also been introduced by Senator Robert Menendez (D-NJ) with seven bipartisan cosponsors (Library of Congress - Thomas, 2009). Despite much public discussion and attention, including public backing from Congressional leadership, including Senate Majority Leader Harry Reid (D–NV), the bill was unable to make it out of Committee in either chamber.

In April 2011, Congressman John Sullivan (R-OK) introduced a revised version of the bill, H.R. 1380, New Alternative Transportation to Give Americans Solutions Act of 20011. As of July 2011, the bill had 183 bipartisan cosponsors (Library of Congress-Thomas, 2011). According to the Congressional Research Service's assessment of H.R. 1380, the bill includes vehicle and infrastructure tax credits. Specifically offering an 80 percent income tax credit for the incremental cost of dedicated NGVs and a 50 percent income tax credit for the incremental cost of bi-fuel NGVs. Full provisions include:

> Amends the Internal Revenue Code to (1) allow an excise tax credit through 2016 for alternative fuels and fuel mixtures involving compressed or liquefied natural gas; (2) allow an income tax credit through 2016 for alternative fuel motor vehicles powered by compressed or liquefied natural gas and make Indian tribal governments eligible for such credit; (3) modify the tax credit percentage for alternative fuel vehicles fueled by natural gas or liquefied natural gas; (4) allow a new tax credit for the production of vehicles fueled by natural gas or liquefied natural gas; and (5) extend through 2016 the tax credit for alternative fuel vehicle refueling property expenditures for refueling property relating to compressed or liquefied natural gas and allow an increased credit for such property. Requires the Secretary of Energy to provide funding to improve the performance, efficiency, and integration of natural gas powered motor vehicles and heavy-duty on-road vehicles. Authorizes the Secretary to make grants to manufacturers of light and heavy-duty natural gas vehicles for the development of engines that reduce

> emissions, improve performance and efficiency, and lower cost. Expresses the sense of Congress that the Environmental Protection Agency (EPA) should streamline the process for certification of natural gas vehicle retrofit kits to promote energy security and provide incentives to encourage and reward manufacturers who produce natural gas powered vehicles. Amends the Energy Policy Act of 1992 to allocate funds for vehicles that are repowered or converted to operate on an alternative fuel (Library of Congress- Thomas, 2011).

Based on the above discussed recommended components of a successful NGV incentive program, the NAT GAS Act of 2011 seems to meet many of the recommended incentive program components. The NAT GAS Act includes significant incentives which significantly reduce payback periods, includes predictable funding opportunities for a specific time period (five years), is on track to be publicly promoted if passed (via programs such as Pickens Plan), and the structure appears to try to reduce administrative hurdles.

The incentives included in the NAT GAS Act of 2011 certainly improve the economics and reduce payback period. Consider the above-discussed payback chart when the proposed credits are included. A tax credit to the purchaser offers a significant incentive by helping to buy down the upfront incremental cost, allowing payback to be realized within the useful life of the vehicle, particularly in the case of dedicated NGVs, such as the Honda Civic GX, which under the NAT GAS Act would enjoy an 80 percent tax credit on the incremental cost. With the tax credit, the payback period is reduced from 27 years to only three years. Bi-fuel vehicles, like the Tahoe used for the road trip, would be eligible for a 50 percent tax credit on the incremental cost, which brings the payback period down to seven years from 19.

	Incremental Cost	Tax Credit	Incremental Cost After Credit	City/Hwy Combined MPG	Annual CNG Fuel Savings	Payback in Years
Honda Civic GX (Dedicated)						
without NAT GAS Act Tax Credit (80%)	$ 6,800	0	$ 6,800	28	521.25	**27**
with NAT GAS Act Tax Credit (80%)	$ 6,800	$5,440	$ 1,360	28	521.25	**3**
Chevrolet Tahoe, Converted (Bi-Fuel)						
without NAT GAS Act Tax Credit (50%)	$ 10,000	0	$ 10,000	16	912.19	**19**
with NAT GAS Act Tax Credit (50%)	$ 10,000	$5,000	$ 5,000	16	912.19	**7**

Assumptions
Annual annual miles traveled of 10,500
CNG price of $2.00/gge; gasoline price of $3.39/gallon (Average prices for first half of 2011)
Similar maintenance costs
Annual Discount rate of 6%

Table 13: Payback for Natural Gas Passenger Vehicles with NATGAS Act

The NAT GAS Act, however, uses tax incentives instead of direct grant programs, which the above-mentioned studies suggested were more effective. The nature of tax credits, however, allows the taxpayer to take a credit against their tax liability, meaning the taxpayer who chooses to take advantage of the incentive and purchase an NGV or invest or natural gas infrastructure, will keep more of their own money, as opposed to receiving a direct grant of new money from the federal government.

It should also be noted that while focus may be on the heavy-duty and fleet opportunity, the NAT GAS Act would benefit the potential passenger vehicle consumer as the incentives for vehicles are not limited by fleet size or vehicle use.

6.5.2.2 Debate Surrounding the NAT GAS Act

The NAT GAS Act, however, has been the subject of recent Capitol Hill debate. Supporters claim the incentives are necessary to kick-start the market and encourage the initial transition. Opponents of the legislation argue the NAT GAS Act favors a specific fuel, natural gas, and picks a winner by skewing the free market. Opponents say their disapproval is consistent with a philosophy of ending all energy subsidies. Supporters of the need for credits, however, have been quick to point out that transportation fuel options and their respective prices are already significantly skewed by a lack of free market principles – oil, for example, is subject to the actions of a cartel, OPEC, and domestic biofuels enjoy mandates, tax incentives, and subsidies. The debate over the act has resulted in significant pressure from certain conservative groups and think tanks, notably the Club for Growth, Heritage Foundation and the American Conservative Union, on conservative and tea party members of Congress to oppose the legislation and pull cosponsor support. As of July 2011, efforts to have initial supporters withdraw their support have successfully pulled 15 Republicans from the list of cosponsor bringing the total number down to 183 (Library of Congress- Thomas, 2011).

6.5.2.3 Opposition to the NAT GAS Act

Opposition to the legislation has come from two main groups: industrial users of natural gas who worry about price increases as a result of increased demand and from the above-mentioned conservative groups who argue the incentives "pick winners" and run counter to free-market principles.

Chemical groups and fertilizer manufactures, such as the American Chemistry Council, depend on natural gas as a feedstock and have made the argument that if Congress artificially promotes demand for natural gas, prices could increase and impact their production costs (American Chemistry Council, 2011).

The argument made against the legislation by conservative groups focuses on free market principles. Nick Loris, a policy analyst for the Heritage Foundation, a conservative think tank, asserts, "if natural gas vehicles are as great as proponents insist, then the industry doesn't need any federal tax incentives to encourage their use," (White, 2011).

Another conservative group, the Club for Growth (CFG), contends their opposition is based on both the distortion of the free market but also a specific section of the Act that mentions greenhouse gases. In a post on the conservative website, Red State, Chris Chocola, head of the CFG, notes:

> Several fiscal conservatives in the House have been duped into thinking this is a good bill but I hope that they immediately withdraw their names as co-sponsors. Putting aside the fact that market-distorting tax credits destroy the system of free enterprise, and are opposed by the Club for Growth, I wanted to highlight one specific part of the bill. Section 403 states, "It is the sense of the Congress that the Environmental Protection Agency['s] new fuel economy and greenhouse gas emission regulations for medium- and heavy-duty engines and vehicles should provide incentives to encourage and reward manufacturers who produce natural gas powered vehicles. Such regulations should take into account the petroleum reductions provided by such vehicles and also quantify all greenhouse gas emission reductions provided by natural gas powered engines and vehicles."

Chocola then argues that by acknowledging the reduced greenhouse gas emissions of NGVs they validate EPA's authority to regulate them:

> In other words, this bill basically lends credibility to the EPA's ability to regulate greenhouse gas emissions, something that many Republicans in Congress oppose. Therefore, the Club for Growth cannot help but conclude that anyone who remains a sponsor of this bill is a supporter of Obama's desire to regulate climate change through the EPA (Chocola, 2011).

In a letter to members of Congress, Gregg Keller, the National Executive Director for the American Conservative Union (ACU), urged members to oppose the NAT GAS Act by making a partisan plea to conservatives ACU supports:

> In recent days, the House has passed a series of excellent bills that would end the Obama Administration's war on domestic energy production, a war that has only increased America 's reliance on foreign sources of energy. HR 1380 does nothing to help that effort. It does nothing to reverse the drilling moratorium. It

> does nothing to open up ANWR to oil exploration. It does nothing to reverse the EPA's attempt to impose draconian regulations on greenhouse gas emissions. That's why so many members of Congress who support the Obama Administration's war on domestic energy production, such as Raul Grijalva, Jesse Jackson, Jr. and Jim McDermott are co-sponsors of this bill. They like the idea of using government power to help decide what people should buy. They like the idea of government picking winners and losers rather than allow a free market to decide the best choice of fuel. But Republicans should know better (Keller, 2011).

He continues by urging conservative members to pull support the bill or face repercussions in the group's upcoming ratings:

> On behalf of the American Conservative Union, I ask that you not co-sponsor this bill and, if you are already a co-sponsor, to ask that your name be removed from the bill. Should HR 1380 come to a vote, ACU will seriously consider that vote for its 2011 ratings. HR 1380, the NAT GAS Act, is the type of special interest legislation the American people said they were fed up with in November (Keller, 2011).

Koch Industries, a Wichita, Kansas based conglomerate with refineries and power production, has also come out in opposition to the NAT GAS Act. In a letter to Congress, Phillip Ellender, president and chief operating officer for government and public affairs at Koch Companies Public Sector LLC, a subsidiary of Koch Industries, said, "we do not believe government should be picking 'winners and losers' in the marketplace," (Snyder, 2011).

Koch Industries' motivation for wading into the debate, however, may be about more than basic free market dogma, and may also be linked to the nature of the company's businesses including refined petroleum products (CNG and LNG are seen as direct competitors to these products) and the use of natural gas as a feedstock of many of their processes (such as fertilizers) (Korosec, 2011). Similar to concerns expressed by the chemical industry, increased demand for natural gas from new natural gas vehicles they worry might put upward pressure on natural gas prices and increase their costs. The connection between conservative groups opposing the NAT GAS Act and Charles Koch and his brother, David, of Koch Industries has also been highlighted as possible motivation for some of the above-mentioned conservative groups' decision to wade into the debate over the NAT GAS Act (SCHO, 2011).

6.5.2.4 Support for the NAT GAS Act of 2011

Despite the opposition of industrial natural gas users and free-market groups, members from both parties of Congress and various businesses strongly support the NAT GAS Act. Congressman John Sullivan (R-OK), the bill's chief sponsor, has pointed out one of the most important aspects of the bill is its potential to "settle the score with OPEC." In Roll Call he wrote:

> We realize that every day we fail to act is a victory for OPEC and a loss for American taxpayers. Currently, U.S. taxpayers are subsidizing foreign dictators by sending more than $1 billion per day overseas for oil. There is absolutely nothing fiscally responsible about that, especially when we have a cheaper, cleaner, more abundant alternative sitting under our feet. The NAT GAS Act is a real solution to a serious long-term energy problem — it's about putting our own energy to good use instead of continuing to invest in foreign energy and job creation overseas. Anyone who saw the most recent jobs report realizes our focus on jobs needs to be right here at home," (Sullivan, 2011).

In response to the pushback of groups like Koch Industries, Congressman Sullivan says:

> Critics [are] searching for arguments against its merits. Most recent is the claim that expanding the market for natural gas will drain the supply, thereby increasing the cost of energy used in manufacturing. This argument might have made sense 20 years ago, but it completely discounts the recent shale gas revolution that has made our country the Saudi Arabia of natural gas (Sullivan, 2011).

Sullivan counters fears that increased natural gas demand for natural gas vehicles will put upward pressure on natural gas prices by pointing to domestic supplies and EIA price forecasts predicting natural gas prices will stay below $6 through 2025 saying:

> Claiming that the NAT GAS Act could raise manufacturing costs again ignores the most aggressive estimates from the EIA predicting the demand for natural gas could increase by 1.25 trillion cubic feet in total usage because of natural gas vehicles — an amount that is less than 5 percent of the 24.45 trillion cubic feet of natural gas the United States consumes each year (Sullivan, 2011).

Sullivan closes his letter by getting to what he thinks is at the heart of opposition:

> At the end of the day, they want natural gas for their own segment of the economy and nothing else. Natural gas is already a fundamental input to nearly every sector of our economy. Limiting its use in favor of any particular sector will only discourage development of this clean domestic resource. Unfortunately, our bill's opponents don't like natural gas for power generation, for export or as a transportation fuel. They would rather hoard it for their own use at the expense of millions of Americans and businesses suffering under the weight of high, unpredictable gas prices (Sullivan, 2011).

Congressman Ron Paul (R-TX) has also been a noted supporter of the NAT GAS Act. Known for his outspoken opposition to subsidies, he has defended his support of the NAT GAS Act by saying:

> While I do not support providing federal grants to any industry, I do support the tax credits contained in the NAT Gas Act, HR 1380. These credits reduce taxes for the production or purchase of vehicles that run on American-made natural gas. These credits are not subsidies (Paul, 2011).

Congressman Paul elaborates on his support, pointing out what he sees as a significant difference between traditional subsidies and tax credits (like those contained in the NAT GAS Act):

> There is much confusion over the difference between government subsidies and tax credits or deductions. The difference is night and day, yet so many times they are all lumped together as evil government handouts. A subsidy IS a government handout. It amounts to the government taking money from the people and giving it to a favored interest. It is the worst sort of market manipulation and it is something I can never support. This kind of government mischief is anathema to the Constitution and the principles of freedom and the free market. By contrast, with tax credits and deductions, industries, business, and individuals simply get to keep more of the money they have earned. Ideally, the tax code should not be used for social engineering, but, until we have true tax reform, I will always support tax credits and deductions that keep more dollars in the private sector where they are spent, saved, or invested (Paul, 2011).

The idea behind the bill has also received support from notable Democrats, including President Barack Obama, who in March of 2011 commended efforts by bipartisan members of Congress to encourage increased use of natural gas vehicles saying:

> Last year, more than 150 Members of Congress from both sides of the aisle proposed legislation providing incentives to use clean- burning natural gas in our vehicles instead of oil. They were even joined by T. Boone Pickens, a businessman who made his fortune on oil. So I ask them to keep at it (NGVAmerica, 2011).

T. Boone Pickens, whose Pickens Plan helped invigorate Congressional support for legislation encouraging natural gas vehicles, has even made a constitutional argument for the NAT GAS Act, by appealing to the Federal government's authority to make policy addressing national defense:

> In Article I, Section 8, the United States Constitution grants Congress the "Power To," among other things, "provide for the common Defense and general Welfare of the United States"; "regulate Commerce with foreign Nations"; and "lay and collect Taxes. While the Constitution does not speak directly to establishing an energy policy, the need for such a policy is certainly implied in the powers granted over defense, general welfare, commerce with foreign nationals, and the laying and collecting of taxes. In April 2011, we spent about $42 billion on imported oil. Annualized, that amounts to half a trillion dollars shipped to such countries as Saudi Arabia, Venezuela, Nigeria, Angola, and Iraq. I can't find anyone who thinks putting our economy ("general Welfare") and energy security ("common Defense") in to the hands of unstable and unfriendly countries such as those ("Commerce with foreign Nations") is a good idea (Dlouhy, 2011).

The bill also enjoys support from a variety of American businesses. In June of 2011, approximately 200 American businesses, associations and municipalities sent a letter to members of Congress urging passage of the NAT GAS Act. Signatories included organizations like BAF Technologies, Blue Bell Corporation, the California Transit Association, Chrysler Group LLC, Dillon Transport, Garden City Sanitation Inc., National Beer Wholesalers Association, Ryder Systems, Inc., UPS, Waste Management Inc., and Yellow Cab Company (Sullivan, American Business Supports the NAT GAS Act, 2011).

In the letter the signatories pointed to the country's dependence on foreign oil and the clean burning benefits of natural gas as reasons the bill should be supported. They repeated earlier calls for passage for the potential economic benefits as well:

> We understand our nation's transportation needs, which we have committed our lives and companies to serving. The NAT GAS Act enables business like ours— ranging from small local and regional providers to global ones— to make the switch that much faster. This support will result in new manufacturing and new jobs, exactly what our nation needs to continue rebuilding our economy (Sullivan, American Business Supports the NAT GAS Act, 2011).

The Center for American Progress (CAP), a progressive think tank, has also weighed in on the NAT GAS highlighting the projected job creation benefits of the legislation. In CAP's analysis of the NAT GAS Act, they anticipate the bill could reduce oil use by at least 1.2 million barrels per day by 2035. Furthermore they note the anticipated job creation benefits of the bill may be more than 100,000 direct manufacturing and labor jobs and more than 450,000 indirect jobs. CAP also sees the effects of high gasoline prices on American families and businesses as added reason to support the NAT GAS Act noting:

> High oil and gasoline prices in 2011 continue to exact a high toll on American families and the economy. They are another reminder—as if one was necessary—that it is imperative to reduce our dependence on this single fuel that powers our transportation system (Weiss & Boss, 2011).

6.6 Conclusions and Summary of Recommendations

While the increased use of natural gas vehicles could result in benefits such as a reduction in dependence on foreign oil, reduced emissions and lower fuel costs, significant obstacles, including inconvenience and higher vehicles costs, continue to inhibit their wider use. There are market trends that suggest a movement towards increased use of NGVS, particularly in the heavy-duty and fleet market, but government incentives, such as the NAT GAS Act, may be needed to jump-start the market.

In the passenger vehicle market, current payback periods mean that consumers will only choose NGVs if they are motivated for reasons other than cost savings. Unrealistic payback periods mean consumers cannot recover the upfront cost of passenger NGVs under current conditions. Presently, vehicle incentives are a must to bring passenger NGVs into a reasonable payback period, and even then it can only be done in dedicated NGVs like the Honda Civic GX.

There is significant bipartisan support for the NAT GAS Act, yet efforts by the bill's opposition make passage less likely. It remains to be seen if the broader arguments for the legislation, including national security, economic and environmental benefits, can outweigh the philosophical arguments against government subsidies. In response to fears about increased prices made by industrial users, supporters of the legislation and the natural gas production industry counter that it's not an either-or proposition, and point to the domestic resources of natural gas as proof that there is sufficient gas to absorb possible increased demand without significantly impacting natural gas prices.

If transportation fuel options accounted for the hidden costs of their use (that is, their market externalities), such as environmental and national security implications, the cost of carbon-intensive, imported oil would be even higher, thereby moving natural gas vehicles into price parity more quickly. Could the cost of the NAT GAS Act tax credits, perhaps, represent those intrinsic benefits to society in the form of reduced health care costs thanks to better air quality or reduced military budgets defending oil interests abroad?

In addition to the benefits a broad incentive program like the NAT GAS Act could afford the natural gas vehicle market (including passenger vehicles), there are additional issues that, if addressed, could impact the development of the natural gas passenger vehicle market.

The build out of refueling infrastructure to support heavy-duty vehicles and fleets must include public access. As the network grows, all potential users (heavy-duty, fleet and passenger) will benefit from the added benefit of additional refueling locations. In addition, home refueling devices appear to offer an attractive option for addressing infrastructure challenges for the passenger NGV market. As additional companies bring devices to the market and customers are offered more options, the home refueling device will increasingly allow users to realize even greater fuel savings over gasoline when paying utility natural gas rates.

While recent changes to federal guidelines for vehicle conversions could help reduce conversion costs, in the long term, OEM participation will be critical to wider use of NGVs for passengers. The development and offering of bi-fuel and multi-fuel vehicles will allow cost savings in CNG component parts (smaller tanks, for example) and empower consumers to make the best fueling decisions.

If the United States wants to displace petroleum with a domestic, cleaner, cheaper, high-performance fuel, then natural gas remains a viable option. But, its success will depend on establishing policy frameworks and market rules that help natural gas overcome its early hurdles and foster an environment where consumers will feel inclined to consider it as another option when shopping for vehicles.

Chapter 7: Conclusion

Abundant and domestic natural gas resources, including the recent addition of American gas shales to total reserves, offer an opportunity for greater utilization of the fuel in the United States, including in transportation markets.

This research in this thesis—conducted through a personal experiment of a cross-country road-trip combined with supplemental analysis—identified many of the opportunities for NGVs and some of the remaining barriers to their widespread use. The benefits over traditional gasoline-powered vehicles include a reduced dependence on foreign oil, reduced vehicle emissions, and possible job creation. As a cheaper alternative to gasoline, NGV drivers could also enjoy significant fuel cost savings. While the focus of expanded NGV use has been on the heavy-duty and fleet vehicle markets, there might also be an opportunity to utilize natural gas in the passenger vehicle market. Government programs to incentivize greater use of NGVs in the United States currently exist, but more could be done such as implementing a comprehensive incentive plan.

A review of passenger NGV costs suggests current payback periods are prohibitively long and outside an acceptable range for consumers. In the short-term and absent government incentives, early adopters will be motivated by more than just economics to justify the move to natural gas. While government incentives would help lower the upfront incremental costs and shorten payback periods, in their absence, there are certain scenarios in the long-term whereby the passenger NGV option could become more attractive. The opportunity for passenger vehicle consumers to take advantage of the NGV option will depend on how the market develops in parallel for heavy-duty and fleet vehicles as well as whether or not technological advancements are achieved in vehicle manufacturing and refueling infrastructure that could help to lower overall costs.

Appendices

Appendix A: Road Trip Companion Website Screenshot

Appendix B: Green American Road Trip Blog Posts

Note: Blog posts appear in chronological order from earliest to latest. All below images are static and hyperlinks and YouTube videos are disabled. To view the videos or live hyperlinks, please visit the archived blog at www.greenamericanroadtrip.com

FEB 16

The Countdown Begins

Leave a comment »

Welcome to my blog! My name is Castlen, and I'm a grad student at the University of Texas at Austin. While there are many great things about being back in school, like cheap tickets to UT football games and the student discounts of my undergrad days, there is a catch. Before UT will give me my diploma, I have to do a thesis. Think back to the longest paper you had to write in undergrad and then add like 100 pages.

So while I will have to do a long written report, I am also going to try to have a little fun. For my research I'll be examining natural gas as a transportation fuel, and in May 2010 I will take a road trip in a natural gas vehicle (NGV) with one of my best friends. We will document the trip and our adventures here, at "The Green American Road Trip."

Thanks for stopping by and come back soon!

FEB
19

Pimp My Ride

1 Comment

The car I will be taking for the trip will be a converted 2009 Chevy Tahoe. Now, I realize a Tahoe may not be the first car that comes to mind when you think "green", so allow me to explain…

The only original equipment manufacturer (OEM) natural gas vehicle (NGV) is the Honda Civic GX. OEM just means it comes straight from the factory ready to go on compressed natural gas (CNG). That's it, no other options here in the US for a brand new natural gas vehicle. And while the Civic GX may be a great little car, the CNG tank can only hold 7.8 gallons.

If you've looked at my map for the road trip (see the "About" page), you know that even with great fuel efficiency I am going to need more than 7.8 gallons to get me from station to station without having to get out and push.

So what's a girl to do? Well luckily, in addition to the OEM option, you can also convert many existing gasoline cars to run on CNG. It requires the purchase of an EPA-certified "conversion kit" and of course the installation which must be done by a certified professional.

But still, why a Tahoe? Why not a small, more efficient car? There are four reasons I am going with the Tahoe. First and foremost, I'm a Texan y'all. Its one thing to show people you can run your car on natural gas but its another to show them you can do it with a variety of vehicle types – and there's probably one that will suit your preferences. If you're from Texas and you like big cars, or you have five kids and you need a big car, CNG will still work for you. You don't have to all pack into a clown car to feel like you are making a good choice.

Second, I need the extra space for tank capacity. Remember 6th grade science class when we learned that gas molecules like to be farther apart than liquid molecules? Well apply that here – CNG takes up more room than gasoline so I need the physical space for the tanks. I'll do a post just on the tanks soon.

Third, I'll be using a domestic fuel, so why not a domestic car. Please don't send me Honda hate mail, I know some are manufactured here but you get my point. I like Hondas, in fact I have an Accord, but for this Great **American** Road Trip, the Chevrolet is a great fit. This collection of Chevy commercials I found on YouTube helps sum up the "American" – Chevrolet connection pretty well. (At least according to Chevrolet!)

And finally, the good people at Apache Corporation who are letting me borrow the car for my trip wanted a Tahoe. They will put it to good use after my trip, and that's the most practical vehicle for their needs. So there you have it. Its been ordered and is being 'converted' as we speak. When its ready, I'll post pics here. Stay tuned.

FEB
22

Conversion: Check!

2 Comments

The Tahoe is ready! Parkway Chevrolet in Tomball, Texas has completed the conversion by installing the compressed natural gas (CNG) conversion kit. Parkway recently became certified in natural gas vehicle (CNG) conversions and can do them on site at their facilities.

After a thorough walk through of the vehicle's features and a peak under the hood, I was ready to take it off their hands!

FEB 26

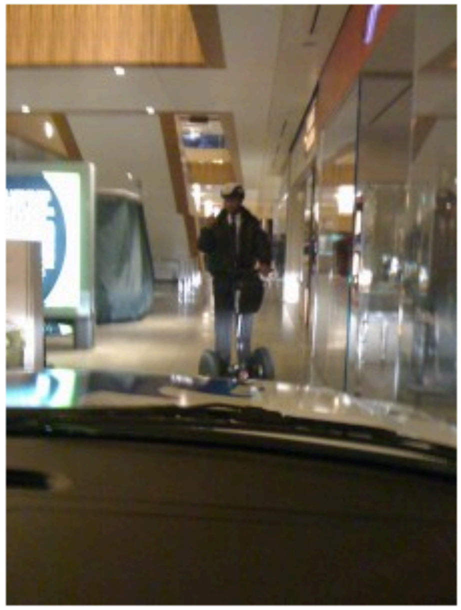
A Fashionable Pit Stop

Leave a comment »

This week, the Tahoe I will be taking for my trip was on display at Houston's Galleria. As part of a conference hosted by the Texas Independent Producer's and Royalty Owners Association (TIPRO), several compressed natural gas (CNG) vehicles greeted shoppers as they walked through the mall including the converted Tahoe, a Honda Civic GX and even a motorcycle.

The motorcycle was actually built for Chesapeake Energy by the guys from Orange County Chopper, you can see a clip from the episode where they built the bike here.

As a side note, we had to drive the cars into the Galleria after hours which was interesting. Especially when this is the guy who is directing you to your designated display spot. Yes, he is on a Segway. He rode backwards the whole way. Impressive.



MAR
2

The first fill up…

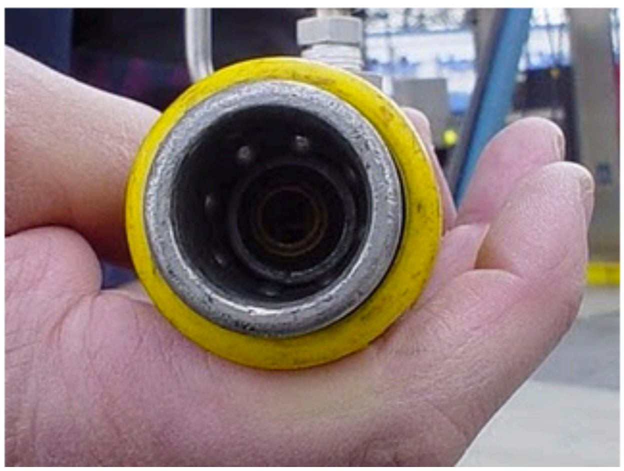
Leave a comment »

I recently had the opportunity to take the Tahoe for its first CNG fill up and took a few photos. A few comments about what CNG actually is…

We're all familiar with gasoline, a liquid dispensed in gallons that flows from the station pump right into our tanks. And most know gasoline comes from oil which is refined into products we can use. So how does CNG differ?

First off, CNG is a gas, not a liquid. Most commonly, natural gas is produced from reservoirs underground but it can also be captured in the form of bio methane (more on this in a later post). You don't have to do much to natural gas before you use it, no refining needed. Before it goes into your tank, however, it is compressed to about 1% of its original volume. Compressing just means the gas is brought under high pressure to really pack it in.

The equipment for refueling is a little different than gasoline in that the hose connects to the car with the nozzle locking in place to create a seal, meaning that during refueling there are no spills or noxious fumes like with a gasoline fill.



The pictures below are from the Clean Energy station on Washington Ave, just north of I-10 in Houston. If your from Houston you have probably passed it before. Its near Memorial Park. The day we filled up, gasoline was selling for about $2.40 a gallon, note the price photo below!


nozzle to it's holder
1.999
PRICE PER
GGE

MAR
8

My YouTube debut…

Leave a comment »

The folks over at ANGA caught up with me in the Galleria recently while the Tahoe was on display. Watch the video below and be sure to check out ANGA's website, its a great resource for those looking to learn more about the benefits of natural gas.

MAR
10

Connecting the Dots

Leave a comment »

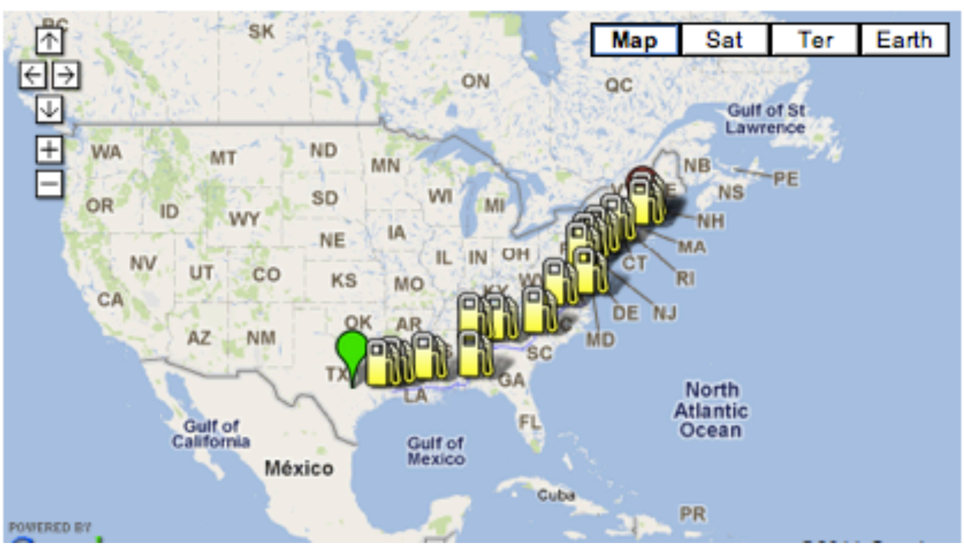
Even though the trip is more than two months away, I have been busy planning for the big adventure. Before I could begin planning some of the more exciting details, like where we'd stop and who we'd visit along the way, I had to make sure the distance was even possible!

According to the Department of Energy there are only 800 CNG stations across the county – compare that to over 120,000 gasoline stations! Certain routes just aren't possible, especially if you have a small tank.

Luckily, there are several online resources to help one figure out just where exactly the elusive CNG stations are located. I used the Department of Energy's site for most of my planning but also enjoyed the maps provided by CNG NOW and CNG Prices.

Once Apache offered me their Tahoe for the trip, I was able to calculate what the vehicle's range would be using CNG, a simple product of the vehicles fuel efficiency multiplied by the tank capacity. That number is critical – if I can't make it to the next station, the trip will be a bit of a disappointment.

I have never been to Boston, and I like the ring of "Austin to Boston" so I began trying to connect the dots between where I live in Austin and the very far away Boston, MA. As luck would have it, it seems to work out with just enough stations exactly where I need them to get me there smoothly. The longest stretches are ironically in areas with tons of natural gas, like Louisiana. But nonetheless I am confident the Tahoe will make it. Check out the maps and see if there are any stations near you. And don't forget to take a look at my route – am I coming through your town?



MAR
13

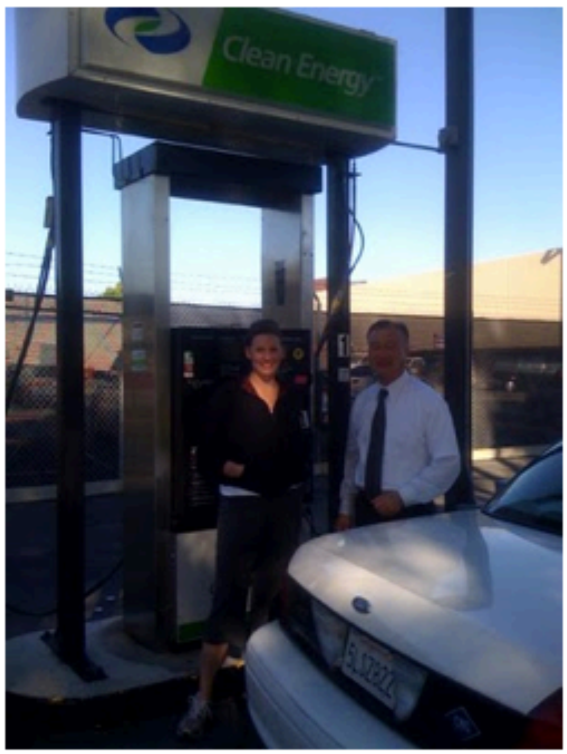
Spring Break 2010

Leave a comment »

One of the great things about being back in school is getting to enjoy a week long vaca over Spring Break. This year I passed on the MTV Spring Break house and opted to visit some good friends in Los Angeles, including Cheryl who will be taking the road trip with me in May.

Interestingly, California just so happens to be a leader when it comes to CNG. For example, they have the most CNG stations of any state at 201, compared to only 23 in Texas. After a hike at Runyan Canyon, Cheryl and I decided to go check out one of the CNG stations in Santa Monica.

At the below Clean Energy station we met James, who purchased a CNG vehicle a few years ago. He seemed pretty content, noting that he enjoyed some nice savings.



The CNG at this station was $2.499 per gallon equivalent. Cheryl filled up about 15 minutes later at a regular gas station and paid $3.11 per gallon for gasoline.

Next we stopped by the local bus depot to check out their fleet: the self-proclaimed "nation's largest clean fleet". Most of them, like the one below, run on CNG. Nice work, California.

MAR 19

Why should you care about compressed natural gas?

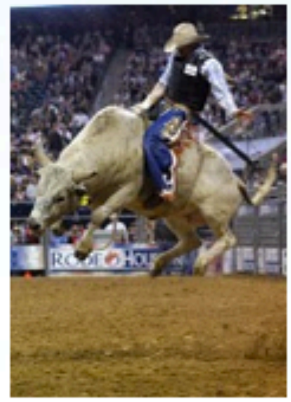
Leave a comment »

Found this interesting video from CNGNow on natural gas for transportation use. I particularly liked the interviews with the fleet drivers. Good summary of the benefits:

MAR 19

Rodeo Time in Houston!

1 Comment



As a native Houstonian, I am a big fan of the Houston Livestock Show and Rodeo. Its the largest livestock show in the world and comes to town every year for 3 weeks. Its an overload for the senses with exciting rodeo events, live music, treats like fried oreos and, of course, the smell of barnyard animals.

Next to the main event, is the exhibit area where you can buy anything from boots to hot tubs. And every year all the big tractor and truck manufacturers have fancy displays with their latest and greatest products. You won't miss the pick-up truck displays, Chevy even has a Silverado chassis on display to give you a sense of all the working parts. (I'm not a car nut so I had to look that word up, but its basically just the frame of the vehicle).

While the trucks aren't being sold new to run on CNG in the U.S., many of these trucks are ideal for conversion. list of trucks and other cars that can currently be converted to CNG.

The last weekend of the rodeo is this weekend, so if you are craving bizarre fried foods you better hurry up! I just got a new Flip video camera for my upcoming trip, and I tested it out last night at my new favorite rodeo event – Mutton Bustin'. Little kids riding sheep and holding on for dear life – hilarious.

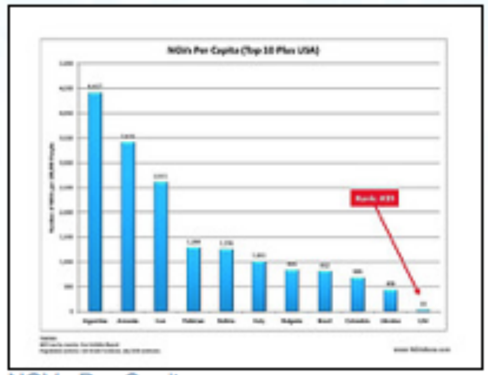
Rodeo photo courtesy of HLSR Facebook Page, Chevy photo courtesy of http://www.chevrolet.com/

MAR 22

How does the US rank in NGVs per capita?

2 Comments

I think this chart is pretty interesting. Natural gas vehicles aren't a new idea and in fact are being embraced all over the world. The US, however, is lagging with a NGV per capita ranking of 39! Its not rocket science, why do you think we are so far behind?



NGVs Per Capita
Originally uploaded by NGVs Now

MAR
26

Mr. NGV goes to Washington

1 Comment

This week the Senate Committee on Environment and Public Works held a hearing entitled, "Opportunities to Improve Energy Security and the Environment through Transportation Policy."

As part of the discussion, the Committee invited the President of Natural Gas Vehicles for America (NGVAmerica) to testify about how natural gas vehicles could be part of the solution.

Two pieces of natural gas vehicle legislation were discussed. S.1809 , the Streamline Vehicles Conversion Act, would help streamline the EPA emissions certification process for after-market conversion systems. NGVA President Richard Kolodziej said, "If passed, this bill would result in the availability of more systems for converting gasoline vehicles to run on natural gas, and they'd be less expensive."

Kolodziej also spoke on S.1408, the NAT GAS Act, which would extend and expand incentives for natural gas vehicle conversions and infrastructure. Both bills also have House companions.

Very cool to see NGVs getting this type of attention on the Hill!

You can watch the full hearing here. You can read the statement of President of NGVAmerica, Rich Kolodziej, here.

What types of incentives do you think are necesary to spur increased use of NGVs?

MAR
31

And then there were two…

Leave a comment »

Big news out of GM this week! According to reports, GM will begin offering CNG-powered trucks in two years bringing the total number of manufacturers offering CNG vehicles in the US to two with Honda. Who will be next?

Here's a brief passage from the article:

"A number of fleet operators want to present a green presence to the public," Rick Spina, GM's vehicle line executive for full-size trucks, told Automotive News. "They want to be known as green companies, especially those on the retail side."

AT&T is one such company — the telecommunications firm reportedly just ordered 8000 Ford E-250 vans, which will be converted to CNG. GM still isn't sure if it will perform the CNG conversion in-house, or subcontract it out to its usual conversion firm, Roush Enterprises. Regardless, the automaker says the conversion requires minimal changes to the existing vehicle.

Click here to read more.

APR 4

A Presidential NGV

Leave a comment »

On Friday, President Obama held a town hall meeting in North Carolina where among other things, energy and transportation issues were discussed. He received an interested question from an audience member about the President's limousines:

The audience member asked if there were plans to utilize hybrid or battery technologies in the President's limousines. President Obama responded that a hybrid limousine wouldn't be feasible in his case because the vehicles are two to three times heavier than a regular limousine with the protections and reinforcements. The heavier the vehicle, the bigger the battery would need to be to provide the power to move the vehicle, similar to why we probably wont see heavy duty trucks powered by batteries anytime soon. Raises an interesting question though – **if the goal is to have a greener fleet, why not convert the Presidential limousines to run on clean, American natural gas?**

You can ask the White House yourself here. I just did.

In fact, there are several limousine companies across the country add green CNG-powered vehicles to their fleets. For example, all limousines at the new City Center in Las Vegas run on… you guessed it – natural gas. You can read about them here.

APR
8

A seasoned road tripper…

2 Comments

I recently wrote an article for the Young Professionals in Energy website on my upcoming trip. Thought I'd share it with y'all here:

I suppose you could say I am a seasoned road tripper. While I don't own an Airstream and haven't been to all 50 states in a Winnebago, I have spent my fair share of time on the road. Growing up, my mom would put my 3 sisters and I into our Econoline van and drive us 10 hours from Houston, TX to Enterprise, MS to visit my grandmother at least once a year. We were lucky as the van not only had a TV and VCR but the third seat rolled out into a bed, a real winner. Along the way, we would make the necessary stops at the Louisiana alligator farms and fresh fruit stands and play the road trip games we all know and love.

In college, I took a road trip with several girlfriends from Austin to Destin, FL with a memorable overnight stop in New Orleans along the way. The highlights of the actual time on the road were mostly stops at fast food places, particularly those that we didn't have in Texas at the time, a la Krispy Kreme and Krystal. Who knew sliders would become so popular?

On the road trips of my youth, I spent my time thinking about what I might be missing back home as my mom dragged me away from my friends over summer break. And in college, my focus seemed to be on making sure I was alert enough to avoid the next state trooper speed trap and geographically astute enough to know just how far I was from the next slurpee pit stop. I rarely spent much time thinking about the "how" of the trip, tailpipe emissions or the significant amount of money we poured into the tank of that gas-guzzling, tv-room on wheels. And yet, in a time of tighter budgets, heightened environmental awareness and those pesky terrorists, the "how" of one of America's favorite pastimes (driving) should get more attention.

This is my look at the "how"…

In my previously mentioned trips, the how was gasoline. For numerous reasons, we aren't supposed to like gasoline, a fuel created from crude oil, but it remains the fuel of choice here in America. And rightfully so. It's relatively inexpensive, and it's easy to find given there is a gas station at nearly every major intersection.

There are alternatives to gasoline, however, and I plan to test one of them out in an upcoming road trip. It's not a sexy, new plant-based something-or-other or even the grease from the Krispy Kreme fryers I mentioned earlier. Rather, its a domestic fuel that burns cleaner than gasoline and costs less; natural gas. Not only is it cleaner and cheaper than gasoline, but it turns out we have a ton of it here in the U.S. Too good to be true? I plan to find out.

The road trip will actually be for a grade – the trip, my documentation of the experience and my final thoughts on natural gas as a transportation fuel will all be part of my graduate thesis at the University of Texas at Austin.

So get ready; I will start my engine in May of 2010 for a week-long trip that will take me from Austin to Boston all on CNG (compressed natural gas). You're invited to follow along as I venture out on a Green American Road Trip – a different fuel but the same good time, complete with slurpee pit stops and maybe even an alligator farm. Follow my adventure at http://www.greenamericanroadtrip.com/

Young Professionals in Energy ("YPE") is a non-profit energy industry networking organization with over 10,000 members worldwide. YPE is dedicated to providing a forum for networking and career development for professionals in the global energy industry. YPE runs a year-round calendar of events in 20 chapters around the world.

APR
9

Greening YOUR ride…

Leave a comment »

I received the following tips on greener driving from Your Daily Thread, an eco blog based out of Los Angeles. Since CNG burns cleaner than regular gasoline, it's an obvious choice for greening your ride but here are a few other simple tips taken from the article that you might find helpful. Full article can be found here.

Green Your Commute
Living life in the fast lane? Perhaps it's time you put on the brakes to pause and consider this from BBC News: in the United States, carbon emissions from transportation (e.g. automobiles) account for about 26% of the national total. For every gallon of gasoline your car uses, about 19 pounds of carbon dioxide are burned and released into the atmosphere, according to an article on The Daily Green.

(Note from Castlen: In CNG vehicles, for every gallon of CNG your car uses about 13.7 pounds of carbon dioxide are released. That's almost 30% less than gasoline.)

While we strongly encourage you to leave the car at home and take advantage of alternative modes of transportation, we're here to recommend some tips to increase your fuel efficiency, save you money and get your car in top green shape in case, like me, you've got one parked in your driveway.

Work It
1. Stop idling. Idling emits about twenty times more pollution than a car traveling at 32 miles per hour, according to Elizabeth Rogers and Thomas M. Kostigen of The Green Book. Next time you find yourself waiting in the car, shut off the engine and roll down the windows.

2. Slow down there, speedster. Rapid acceleration and braking can decrease fuel economy by 33%.

3. Instead of washing your car at home, take it to the car wash. Commercial car washes use about 100 fewer gallons of water than washing your car by hand (The Green Book). In addition, they often recycle and reuse their water. Water used is required to be drained into the sewer so it can be treated properly. Before heading out, however, find out if your local car wash is as squeaky clean as they claim your car will be, by making sure it complies with environmental, labor, health and safety laws.

4. Make sure your tires are properly inflated to improve your gas mileage by more than 3%.

5. If your car doesn't require the use of high octane gasoline (i.e. "premium" with a 92 or 93 rating at the pump), don't use it. Not only is high octane more expensive, it requires the use of many "toxic substances" to create it, which are then released into the environment. To find out the type of gasoline your car requires, check your owner's manual.

6. Ride with an amigo and help save up to 500 gallons of gasoline and 550 pounds of poisonous exhaust emissions every year (The Green Book). Commuters sharing a ride to work would be the equivalent of taking 67.5 million cars off the road

APR 15

CNG Shout Out

Leave a comment »

Apache CEO, Steve Farris, on CNBC this morning mentions natural gas vehicles and the role they could play in the future:

APR 16

A CNG Critic

Leave a comment »

Watch the below interview with Charles Drevna, President of the National Petrochemical and Refiners Association, as he discusses natural gas as a transportation fuel. He makes some good points, but then again, he represents refiners who make gasoline. What do you think?

APR
19

Trip prep continues… one month to go!

2 Comments

Part of planning a CNG road trip involves lots of time on the phone, calling CNG stations along my route to verify I will be able to refuel there, hanging up and then calling again a week later to verify the same thing all over again. While calling gas stations ahead of time is certainly not your your typical road trip planning exercise, I am hearing great stories and making friends already! Everyone has been so helpful, and I really appreciate everyone's enthusiasm and support.

In addition to calling stations, I have been reaching out to various individuals, companies and facilities along my route who would be willing to chat with me about their experiences, good and bad. One of the great stories I have come across so far comes from two self-proclaimed "knuckleheads" in Birmingham, AL. To learn more about their decision to convert their airport shuttle business to run on CNG and their later decision to plan a road trip of their own on Route 66 check out their website. And make sure to follow my blog when the trip starts as I will be telling their story and many others!

APR
22

Practice Makes Perfect

3 Comments

Apache lent me the Tahoe this week so that I could get used to driving it and practice refueling. Unfortunately, that's turning out to be more challenging than I thought. The car is currently out of CNG, so I decided to go to the **one** CNG station in Austin this evening to fill up.

I have filled up before but not at this station. Nonetheless, its not rocket science, and I'm usually pretty good at following instructions. I followed the printed instructions and was even required to watch a brief safety video, but I just couldn't get it to work. What was nice about this station though, is that there is a help phone. I picked it up, and it immediately connected me with a nice lady who paged the local tech. He then called me back on the same phone a couple minutes later.

He said he could see on his end that I wasn't properly connected. After removing the pump, and trying to reconnect half a dozen times, I gave up. I was pretty frustrated. I am going to get up early tomorrow and try to be there when the City's trucks are refueling. Hopefully, someone can help me. Has anyone filled up at that station? Any thoughts on what I might be missing?

APR 26

Increasing gasoline prices just in time for summer

Leave a comment »

I came across the below article this morning on rising gasoline prices. I figure this a good opportunity to look at the difference in cost in CNG versus gasoline. The most recent data from DOE is from January, but the numbers are interesting.

Table 2. January 2010 Overall Average Fuel Prices on Energy-Equivalent Basis

	Nationwide Average Price in Gasoline Gallon Equivalents	*Nationwide Average Price in Diesel Gallon Equivalents*	*Nationwide Average Price in Dollars per Million Btu*
Gasoline	$2.65	$2.96	$22.99
Diesel	$2.57	$2.87	$22.26
CNG	$1.85	$2.07	$16.07
Ethanol (E85)	$3.36	$3.75	$29.13
Propane	$4.13	$4.61	$35.81
Biodiesel (B20)	$2.70	$3.02	$23.44
Biodiesel (B99-B100)	$3.54	$3.95	$30.67

According to the chart, CNG is selling at a 30% discount to gasoline. Good thing my summer travel plans include a road trip on CNG and not gasoline.

Gas Prices to Increase for Summer Vacation

Strengthening Economy Will Lead to More Money at the Pump, Experts Say
By MARK TRUMBULL
April 24, 2010—

Drivers beware: Gas prices may be heading up this summer, thanks largely to signs that the economy is strengthening.

That would follow a typical pattern in which gasoline prices often peak during the season of maximum demand. The big question, of course, is how high prices will go.

Energy prices are notoriously volatile and hard to predict. For now, many forecasters see a moderate rise — not the major spike that walloped American consumers in 2008.

Here's more on the outlook and what it might mean for you:

The U.S. average retail price will peak this summer at slightly above $3.10 per gallon, predicts Patrick DeHaan, who tracks the industry as a senior analyst for GasBuddy.com. That would be up about 8.5 percent from the beginning of this month, according to the U.S. Energy Information Administration.

To read more, click here.

MAY
3

Fuel Prices: Part II

7 Comments

As a follow up to my earlier post on the cost savings of CNG over gasoline, I thought I'd share my estimates for the upcoming trip.

The converted Chevy Tahoe I am taking on the trip has a 22.5 gallon of gas equivalent (gge) capacity, the standard on a gasoline-powered Tahoe is a 26 gallon tank, so its smaller but not too far off. The fuel economy is about the same with either fuel getting 15 city, 21 highway. For my estimates, I am using 18 mpg as an average. I think that's actually conservative since most of the driving will be highway.

A note about capacity: the standard conversion for a Tahoe would usually be two 4.5 gge capacity tanks attached to the undercarriage. This would have given the Tahoe a range of only 9 x 18= 162 miles which wouldn't have gotten me very far. Apache added 3 additional CNG tanks (4.5 gge capacity each) to the rear of the vehicle and removed the 3rd seat, greatly extending the vehicles range.

So with those details: The modified Tahoe's range on a full tank = 22.5 x 18 = 396 miles per full fill

And using the national average prices from DOE. (The most recent data for average CNG prices is for Jan 2010 so I used that for both fuels)

Estimated Costs per Gallon:
Gasoline = $2.65/gallon
CNG = $1.85/gge

Estimated Miles Travelled:
Direct route from Austin to Boston = **1,998 miles** (according to Google Maps)
My route with added diversions to get to the CNG stations = **2,344 miles** (Note: this is just fueling station to fueling station – the actual final mileage will be more because of some of the additional stops we will be making along the way)

So my estimated cost comparison calculation looks like this:
- On gasoline = 1,998 mi / 18 mpg x $2.65= $294.15
- On CNG = 2,344 mi / 18 mpg x $1.85 = $240.91

So even though I have to go 346 miles out of the way, I still save $53.24 on fuel! I will be keeping detailed accounts of this on the trip and will share the actuals with you all as we go.>/p>

MAY
14

Less than a week to go…

5 Comments

I have finished up my finals for the semester, and am tying up loose ends before we hit the road next Wednesday! Planning of late has been focused on confirming and finalizing meetings along the way, getting our hotel reservations in order (the cars great – but I don't want to sleep in it!), as well as putting together road trip music playlists! I have also finalized details on some great events that any and all are welcome at!

AUSTIN: Join us at the LBJ School of Public Affairs at 8am on Wednesday, May 19th as we bid farewell to Austin and kick-off our 2,300 mile journey towards Boston. You can get full details on the Green American Road Trip Facebook page.

HOUSTON: If you are in Houston later that day, you can come say hello and check out the car first hand at the Young Professionals in Energy Happy Hour at 5:30 at Pub Fiction in Midtown. Full details here.

I will post more opportunities to see us along the way as they come together!

MAY
19

This is it!

10 Comments

Good morning! Well, its finally here. The road trip send-off event is this morning at 8am, and I am already up and at TX Gas Service in Austin for some pre-trip interviews. This is going to be a great day, and I thank everyone for helping me put it together and supporting the trip! As I travel across the country I will be posting my adventures here and using Twitter and Facebook as well. So please follow along, send me your questions and spread the word! And if you havent already – enter the contest!! I am giving away an iPad to my Twitter followers. You can click on the tab at the top for more info on how to enter. Thank you NGVA for the donation! See you on the road!

MAY
19

Day 1 Wrap Up

Leave a comment »

Here is the video we made out at Parkway Chevrolet. Includes a tour of the Tahoe:

And here is the wrap up video we made at the end of the day:

MAY 20

Road Trip Itinerary

Leave a comment »

So we had a successful and safe first leg of the journey and are now well rested and headed eastbound towards cajun country!! We took some good video yesterday that included some great interviews, so make sure to check out the youtube videos we are posting.

The trip is 10 days total, 2,300 miles in all. Here are the details of where we will be:
Austin (Wed, May 19)
Houston (Wed, May 19 – Thurs May 20)
Lafayette (Thurs, May 20)
Baton Rouge (Thurs, May 20 – Fri May 21)
Birmingham (Fri, May 21)
Atlanta (Sat, May 21)
Athens (Sun, May 23)
Hickory & Chapel Hill (Sun, May 23)
Norfolk (Sun, May 23)
Washington DC (Mon, May 24)
Baltimore (Wed, May 26)
Philadelphia (Wed, May 26)
NYC (Wed, May 26)
Boston (Thurs, May 27 – Fri, May 28)

Are we coming through your town?

Here is me filling up in Houston this morning as we hit the road.

MAY 21

Day 3: Baton Rouge to Birmingham

Leave a comment »

We spent the night in Baton Rouge last night after a full day or driving and stops, including a tour of an LNG import facility. Today I'm meeting with representatives of the Louisiana Dept of Natural Resources and the Department of Environmental Quality. I hope to learn about CNG related activities in LA and some of the great incentives that are helping make those possible. From Baton Rouge we'll get back on I-10 and head through MS and AL with a slight detour into the FL panhandle for our next fueling stop. Then it's off to Birmingham!

The last time I filled up was in Beaumont, and since them I have travelled 225 miles, and I have just under a half a tank left! Not bad, we'll fill up here in Baton Rouge this morning before we leave. The haul to the station in FL is one of our longest!

MAY 21

Filling up

2 Comments

This is a video from the fill up yesterday at the Clean Energy station in Houston.

MAY 21

Well I didnt plan for this… Leave a comment »

As many of you know, this trip has required a ton of planning. I routed out the map months ago and called all the stations to verify they were public and find out what form of payment they would accept. There are some things, however, you just can't plan for.

I posted a note on Facebook today about the station we filled up at in Baton Rouge. While the techs were quick to respond, we got an error msg on the pump and had to wait for them to come out and reset it. That set us back a bit.

But after leaving Baton Rouge shortly after 11am and stopping for a bite to eat, we encountered the worst traffic jam I have ever been in. We were en route to Milton, FL (about 250 miles away) for the next fill up. Turns out an 18 wheeler carrying a large engine overturned, and forced authorities to completely close the freeway. And we were left with no choice but to just sit and wait it out for several hours. Now in a gasoline car, this would certainly be annoying but not the end of world.

Here is the problem – Milton's station is opperated by the city and when the city closes (4:30 on Fridays) so does the station. You can come after hours but only if you have given them a $50 deposit and received a special access card. We called the City several times to ensure it was working but were transferred to a voicemail each time we called.

We have now confirmed by talking to the Milton Policy Dept that the station is closed, and here we are still about 1.5 hours away. We are going to go ahead and head there and hope for a miracle… **If you happen to live in Milton and have a special access card, help a girl out!** You can send me an email at castlen@greenamericanroadtrip.com

Will post an update when we get there.


MAY
22
We Made it!
Leave a comment »
...here's how the previous post unfolded.
YouTube
0:00 / 0:00

MAY
22

Day 4 Update

4 Comments

Yesterday was by far the most "exciting" day of the trip. The video from the below blog post illustrates one of two big challenges we ran into yesterday. As I mentioned earlier, the 18 wheeler accident resulted in us sitting on I-12 for about 3 hours. We couldn't just turn the car off and sit though – we would sit still for a minute then roll forward 5 feet or so and stop again. We went about 12 miles in 2.5 hours before they finally diverted us off the highway.

The first problem with this was the amount of fuel we wasted idling. We had been counting on a full fill getting us about 350 miles, BR to Milton never seemed like it would be a problem.

Idling, however, can have significant effects on fuel economy. I found this interesting fact today from the California Energy Commission: For every two minutes a car is idling, it uses about the same amount of fuel it takes to go about one mile.

We probably idled for about 150 min, or in other words, we wasted about 75 miles worth of fuel inching along a 15 mile stretch of highway. (This assumes the CEC info can be equally applied to vehicles running on CNG – I am going to assume yes since they get similar fuel economy.)

So the earlier video shows the excitement of simply making it to the Milton station. When we are low the indicator light flashes to tell me we are running on reserves. Yesterday it flashed for the last 40 minutes of the ride, but never began beeping which is when you know you have run out.

The second big problem was that it put us way behind schedule. A lack of infrastructure, or refueling stations, is definitely a problem for CNG vehicles, but it's also a problem when while there may be one in an area you need, it closes at 4:30pm on a Friday like the Milton station.

Once we actually got over the joy of making it to the station on CNG, we had to deal with the fact that according to chat rooms and late confirmation from an individual with the City of Milton, the station "closed" at 4:30 on Fridays and would not reopen until Monday morning.   The sign at the station, however, says, "Open 24 hours" and "Public Welcome", and my prep calls to the station in the weeks prior never included any info about needing a special access card once the wknd rolled around.

So we went ahead and tried to fill up, thinking we'd be out of luck. We were all praying for a miracle, and when we turned it on the sweet sound of gas rushing into the tank began. That video is even more dramatic than the other. Take a look.

The predicament, however, was that while it worked it never registered my credit card and therefore never charged me. Leading me to believe that this unmanned station "closes" at 4:30 when they turn the credit card reader off.

This whole situation though seems very weird to me. Many regular gas stations and the Clean Energy stations, for example, have 24 hour card readers. This leaves a CNG user passing thru Milton after hours with 2 options: just get stuck and hang out til Monday morning when the City opens back up for business or pump your CNG but have no way to pay for it. We took down exactly what we received, 13.965 gallons of gas equivalent at $1.39/gallon, for a total of $19.42, and I'm going to mail pymt to the City today. Thankfully, it all worked out and we were able to continue on to Birmingham as planned, just way later than expected!

MAY 23

Workin' Through the Weekend

1 Comment

Saturday we left our Birmingham hotel early and headed to the one CNG station in town to fill up, only a $1.369 a gallon of gas equivalent. While we were there we met a small business owner, Libby McConville. Libby and her husband, Mark, own Airport Express, which provides shuttle rides from Birmingham to the Atlanta Airport. They decided to start using CNG for two of their vans just recently. Here is her story:

We then went by a natural gas pipeline compressor station in Tarrant, AL. This facility is operated by El Paso Corporation, which owns the nation's largest natural gas pipeline system. This was an interesting stop because we learned about the extensive natural gas pipeline network that spans the country moving natural gas from the areas where it is produced to the areas where it is needed.

From the natural gas vehicle perspective, I think this is interesting because while we need more refueling infrastructure, the pipeline infrastructure needed to move it around the country is already present. You can't say that for other alternative fuels, like ethanol, which for extensive, large scale distribution will need pipelines.

I pulled up some details on the U.S. natural gas pipeline network from the US Energy Information Administration. The US pipeline system includes 305,000 miles of interstate and intrastate transmission pipelines, 1,400 compressor stations, 11,000 delivery points, 5,000 receipt points, 400 underground natural gas storage facilities, 49 locations where natural gas can be imported/exported via pipelines and 8 LNG (liquefied natural gas) import facilities (like the Cameron LNG facility we visited on Thursday.)

We then headed on towards Atlanta, only a couple of hours away – nice change from Friday's long day of driving. When we arrived we met Ian Driskill with AGL Resources, the local gas supplier in Atlanta. Across the street from their downtown offices, AGL has a parking lot with a CNG refueling device, a FuelMaker "Q" series vehicle refueling appliance (VRA). This is a time-filled device, meaning it fills at a slower rate than a large refueling station, pumping about a gallon an hour into the vehicle. He let me back the Tahoe in to hook it up and refuel overnight. This is a video of Ian explaining how this device works:

Next we headed over to check out Atlanta's public bus fleet, operated by MARTA. Nearly 2/3 of Atlanta's buses run on natural gas instead of diesel, making them one of the largest clean fleets in the country. They have a huge facility where they store the buses and refuel them.

MAY 24

Can your gasoline car do this?

2 Comments

So while today is mostly a day of driving with two stops for fuel along the way, we also made a cool stop in Athens, GA this morning. In addition to being able to refuel at CNG stations, there are also home fueling devices which allow you to tap into the natural gas already running into your home to fuel the water heater, stove, etc. I think the ability to fill up at home is one of the most interesting aspects of the natural gas vehicle.

Georgia Green Fuel, LLC is the local distributor for the Fuelmaker Phill home fueling device. George and Leon of the company met us at the home of Leon's daughter, Brittany, to show off the device and explain how they work.

George also drives a Honda Civic GX and was nice enough to show us the car and how it differs from the standard Honda.

And here is a clip of Brittany showing us how she fills up her car.

For more info on the home fueling device you can check out the manufacturer's website, IMPCO Technologies. I also did a quick search on eBay and found a used one for sale.

MAY 24

Half Way Point Update

6 Comments

We are now in Day 6 and are over half way done with our 10 day, 2,300 mile trip!

We got in late last night to Norfolk, VA after a big day of driving. We filled up twice along the route from Atlanta to Norfolk, once in Hickory, NC ($2.32/gge) and then again later in Wake Forest, NC ($2.00/gge).

As we were headed to Wake Forest to top off before we made the final stretch to Norfolk, one of our Facebook friends reached out to us and invited us to come by his Subway to have dinner on him. We went by to see Nasir and his family and showed them the Tahoe. Nasir was telling us how common CNG vehicles are in Pakistan and said he couldn't understand why we aren't using them more in the US. One difference between the US and Pakistan is the cost to convert – thousands in the US and only a fraction of the cost in Pakistan. We have a couple meetings planned with Embassies while in DC to hear about how other countries have encouraged CNG use in their home countries. Maybe we can learn something from them... Thanks again, Nasir, for dinner!

This morning we filled up at the Norfolk station ($1.542/gge), but we had to be met by an employee because a key card was needed. Thanks to Virginia Natural Gas for meeting us out at the station this morning.

Next we headed over to Newport News, VA for a meeting with Virginia State Senator, Frank Wagner. Senator Wagner has been a vocal advocate for expanded use of our domestic resources. In addition to some cool scenery, we talked about the national security implications of our dependence on foreign oil and the amount of money that dependence costs the US.

We are now in route to DC. We just finished up a quick detour over to Colonial Williamsburg, here we are, "prisoners to foreign oil". More to come from the Nation's capitol!

MAY 26

Update from the Nation's Capitol

5 Comments

We are winding up a 2-day stop in Washington, DC and after a couple of meetings this morning will head out towards NYC.

We arrived on Monday afternoon and filled up in northern Virginia, right outside of the Pentagon at a fueling station for Navy personnel. If you are looking for CNG though they will allow anyone to fill up. They did not post the CNG price ($2.419) but you can see how it compares to other fuel prices at the same location.

Next I stopped by Dow Chemicals offices for a chat about using natural gas as a transportation fuel. Dow sees the issue from a different perspective as a large end user of natural gas. They use natural gas not only as a fuel for power generation at their plants but also as a feedstock for many of their products. There seems to be concern on behalf of other natural gas users like Dow, that encouraging natural gas for transportation use will increase demand and drive up prices. This is a very valid concern but it raises the question – do we have enough to do it all?

I found this article about supply which speaks to how much we have and what that may mean for expanded use. It included this quote from a Professor at Rice University:

Recent technological innovation has transformed the natural gas exploration and production industry, particularly as it pertains to shale. The findings in this study indicate significant potential for expanded use of domestically produced natural gas for many purposes, including power generation and even transportation fuel for many years to come.

—Dr. Kenneth B. Medlock III, co-author and professor of economics at Rice University
Here is another thought that my thesis advisor mentioned in a recent meeting... we typically think of increased demand for a product as a trigger for rising prices. But you could also argue that increased demand and price will incentivize natural gas producers to find and produce more product. Demand and increased activity could lead to improved technology and a more stable price. Do you think we have enough to do it all?
On Tuesday, we began the day with a conversation with a few of the gas trade associations to get their thoughts on using natural gas as a transportation fuel. They were very interested in the refueling challenges we have faced along the way, and I plan to summarize my thoughts to share with them once the trip wraps up.
Next we headed to Capitol Hill and after the car got the okay from the K9 unit, we drove the vehicle up to the House Office Buildings to display it for Members of Congress and staffers.

We had some good interest, and I answered a lot of questions about the vehicle and conversion as well as the trip so far. Here is a photo of me giving Congressman Dan Borenof OK a tour of the car. Congressman Boren is a sponsor of the NAT GAS Act which would increase incentives for vehicles and refueling infrastructure. For more info on his bill, click here.

As we were getting ready to go, one of the Capitol Police officers walked over for a tour. He said they were actually ordering new crusiers for their officers and had considered natural gas vehicles but had concerns about where they would refuel. I have heard that before.

Next stop was to head over to see Capitol METRO at one of the large bus maintenance facilities. The folks at METRO were very nice, and in addition to giving us a tour of the facility and thier CNG refueling infrastructure they had set up multiple versions of the CNG buses they run to show the various engines. The best part – they let me keep that awesome vest.

After hearing about the naturla gas busses in DC, I headed over to meet with former Secretary of Transportation, Norman Mineta. It was a great honor and he shared some of his experiences while he was head of DOT. We talked about fuel economy standards as well as safety concerns related to natural gas vehicles.

To sum up, I did a wrap up video along the Potomac.

MAY
27

How clean is your tailpipe?

1 Comment

After leaving DC yesterday, we stopped by the Clean Energy Station in Baltimore near BWI to top off the tank as well. This station is not open to the public, but Clean Energy agreed to meet us there to let us refuel. We would have made it to NYC without the stop, but whenever there is a chance to top off with CNG, I have learned you should take it. Our friend from Clean Energy drives a dedicated van (meaning it ONLY can run on CNG, unlike our Tahoe which is dual-fuel). The van has 65,000 miles on it and in this video he is showing off the tailpipe and how clean it is. I dare you to go run your fingers through the exhaust pipe of your car – I doubt it will look like this

We are in NY now, and I'm actually doing this post from the Bronx Zoo parking lot. We are about to head in to 1) check out the animals and 2) check out the zoo trams which run on CNG!

MAY 27

A fillup hiccup

5 Comments

On our way out of New York this morning we went by the Clean Energy station at La Guardia Airport. This station is actually a pump at a larger BP gas station. I identified this stop months ago and had confirmed that it was open to the public and accepted MC/Visa and not a special type of pymt card over the phone.

I am learning that their are other questions you need to be asking though when you call some of these stations ahead of time, such as "is their ANYTHING else I need to know before I come that would prevent me from getting fuel??" When I arrived,I went inside to pay and while yes, they would take my VISA debit card for pymt, before the BP attendant would sell me CNG I had to show him my "CNG Certification Card". Say what? I have never heard of these, and here I am at what will probably be my last stop for fuel on a 10-day, 2,300 trip and this is the first time someone has asked to see my certification card. Maybe this is a NY State rule, I have no idea.

He told me that you have to complete a training to ensure you know how to use the pump, which sounds like a great idea but would have been nice to know before I pulled in to the station.

There was actually a Clean Energy tech on site so he called his boss and got permission to pump it for me. Now, that was lucky, if the guy wouldn't have been there I would have needed to get the card before I could get the gas. Here is a video of me at the station explaining the situation. I was a little agitated when we shot it, but not angry at the Clean Energy tech – he was the one who saved us.

UPDATE: I got a call from Clean Energy in NYC a few minutes ago and they said that the City of NYC requires users of CNG to take a one hour course in person at one of their facilities. There is an effort to repeal this requirement as its seen by many as an outdated law no longer needed given the safety and advancements in the refueling infrastructure. ae, a bit of a hurdle if you are passing through NYC and need CNG.

MAY
28

We have arrived in Boston!

1 Comment

We have arrived in Boston!! We drove into town this afternoon completing our multi-city, 2,575.6 mile journey from Austin on natural gas!

This trip has been wonderful, and we met so many interesting people along the way who shared their stories and experiences with us as we made our way across the country. We heard from hopeful enthusiasts, skeptics, policy makers and friends along the route, and we greatly appreciate everyone's time and support of our efforts.

During the trip, we had a vehicle follow us for safety reasons and to help document the trip, and while it too was a converted, dual-fuel CNG vehicle we opted to have it run the trip on gasoline so that we could have a handy comparison when we wrapped up. I have done a quick analysis of the trip, and compared our stats to the stats of the vehicle that followed us. Here are the highlights:

2009 Chevy Tahoe on CNG:
Total Fuel Cost: $285.79 for 125.57 gallons of gas equivalent, with an avg mpg of 20.51 and an avg cost of $.11/mile.

2009 Chevy Avalanche on gasoline:
Total Fuel Cost: $426.80 for 160.6 gallons of gasoline, with an avg mpg of 16.03 and an avg cost of $.17/mile.

Overall, we saved $141.01, or 33% by using CNG instead of gasoline.
The fuel savings are impressive, but the fuel economy is what really stands out. I have always been told that the fuel economy was comparable with perhaps a slightly better number for CNG on the highway – this is better than I anticipated however.

We took our savings and headed to Fenway Park. We were able to score 2 seats, and had enough left over for ballgame snacks and even a baseball hat souvenir.

Tomorrow we head back home, and I will be back with a summary of my overall impressions of the trip and what its like to drive a CNG vehicle. Thanks for following the trip!

Note: these are my initial quick calculations, and I will do a more thorough analysis when I get back home. These numbers do not account for the unused fuel that remains in the tanks of the two vehicles.

Appendix C: Green American Road Trip Facebook Screen Shot

https://www.facebook.com/greenamericanroadtrip

Screenshot as of July 10, 2011

APPENDIX D: GREEN AMERICAN ROAD TRIP TWITTER FEED

Selected tweets from Green American Road Trip (May 2010 – June 2010)

Castlen Kennedy

@castlen Houston, TX

Tweeting about energy, politics and all things Texas! The views expressed here are strictly my own.

http://www.greenamericanroadtrip.com

About @castlen

758	516	1,134	36
Tweets	Following	Followers	Listed

castlen Castlen Kennedy

Eating at America's oldest restaurant with @cheryldalton before we head back home! — at Union Oyster House http://gowal.la/v/c/PyHd/tw

28 May 10 Favorite Reply Delete

castlen Castlen Kennedy

We made it to Boston!!! 2,575.6 all on #cng #celebrate!!!

27 May 10 Favorite Reply Delete

castlen Castlen Kennedy

"Welcome to Massachusetts!" the #greentrip is an hour from Boston! Austin to Boston on #cng!!

27 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Next stop: BOSTON!! #greentrip

27 May 10 Favorite Reply Delete

castlen Castlen Kennedy

turns out NYC actually has 3,300 CNG Cabs (via @NGVsNow) - much better than 5!

27 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Checking out the animals and #cng shuttles at the Bronx Zoo http://twitpic.com/1rjqpb

27 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Surprising stat: there are 13,327 taxicabs in NYC and only 5 run on CNG. #greentrip

27 May 10 Favorite Reply Delete

castlen Castlen Kennedy

In NYC having dinner with old friends from TX! — at Gemma http://gowal.la/v/c/P5cs/tw

26 May 10 Favorite Reply Delete

castlen Castlen Kennedy

@NGVsNow @CNGnow do y'all know how many taxicabs in NYC run on #cng?

26 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Entering the Lincoln tunnel http://twitpic.com/1rd30z

26 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Almost to NYC - less than an hour and the #greentrip arrives in the big apple!

26 May 10 Favorite Reply Delete

castlen Castlen Kennedy

just uploaded some new pics to my Flickr page! http://www.flickr.com/photos/greentrip/

26 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Welcome to Delaware and another toll! #greentrip

26 May 10 Favorite Reply Delete

castlen Castlen Kennedy

On the way to NYC, stopping for sandwich! — at Panera Bread
http://gowal.la/v/c/NZ8P/tw
26 May 10 Favorite Reply Delete

castlen Castlen Kenned
Going to Baltimore, MD to fill up on both CNG and food. Any suggestions for a great place to eat?
26 May 10 Favorite Reply Delete

castlen Castlen Kennedy
Just arrived at the Italian Embassy in DC to talk #NGVs in Europe!
http://twitpic.com/1r9k1q
26 May 10 Favorite Reply Delete

castlen Castlen Kennedy
Just finished up at the Embassy of Brazil. Very interesting. Learned that over 90 percent of taxis in Rio run on CNG #greentrip
26 May 10 Favorite Reply Delete

castlen Castlen Kennedy
Day 8 of the road trip - headed to NYC today but thinking a detour through Maryland for crabs is in order!
26 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Showing my roadtrip friends @chadosko @eblakejackson @cheryldalton around DC #greentri — at @oldebbitt http://gowal.la/v/c/NNar/tw

25 May 10 Favorite Reply Delete

castlen Castlen Kennedy

It was an honor to meet former Secretary of Transportation Norm Mineta #greentrip http://yfrog.com/jkmcfjj

25 May 10 Favorite Reply Delete

castlen Castlen Kennedy

There's lots of fun ways to follow my trip: Facebook, YouTube, Flickr, etc. Find them all on my blog! http://www.greenamericanroadtrip.com/

25 May 10 Favorite Reply Delete

castlen Castlen Kennedy

At the DC Metro Bladensburg division bus station. They currently run 461 CNG buses! #greentrip

25 May 10 Favorite Reply Delete

castlen Castlen Kennedy

it was great meeting Congressman John Sullivan and chatting with him about #CNG! http://twitpic.com/1qywce

25 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just finished showing Congressman Boren around the Tahoe. #greentrip http://twitpic.com/1qy7qt

25 May 10 Favorite Reply Delete

castlen Castlen Kennedy

The Tahoe going through a K-9 sniff test before heading up to the capital. The dog even had a badge. http://twitpic.com/1qy26i #greentrip

25 May 10 Favorite Reply Delete

castlen Castlen Kennedy

First stop of the day, @ANGAus

25 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Dinner in DC with @chadosko and @ cheryldalton — at Zed's Ethiopian Cuisine http://gowal.la/c/Nx4q

24 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Made it to the DC area, filling up w #CNG for $2.419/gallon — at NEX Navy Exchange Gas St http://gowal.la/c/NtA3

24 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Quick detour in route to DC — at Colonial Williamsburg

http://gowal.la/c/Nr3r

24 May 10 Favorite Reply Delete

castlen Castlen Kennedy

The Garmin GPS has saved us on this trip!!! Thanks again

@BestBuy www.greenamericanroadtrip.com

24 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just filled up at Virginia Natural Gas in Norfolk. On our way to Washington DC. http://twitpic.com/1qls0v #greentrip

24 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Hello Norfolk #greentrip

24 May 10 Favorite Reply Delete

castlen Castlen Kennedy

...make that 79 cents per gallon, but still! http://twitpic.com/1qinwo

23 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Thanks @subwayfreshbuzz and Haw River storeowner, Nasir for the free dinner! Great to meet fellow CNG advocates http://twitpic.com/1qi22u

23 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Free sammy from Nasir! Thanks @subway! #cng is getting us free meals along the #greentrip — at Sunway http://gowal.la/c/NimD

23 May 10 Favorite Reply Delete

castlen Castlen Kennedy

First rain of the road trip plus a rainbow http://twitpic.com/1qh3er

23 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just filled up w/ #cng, $2.32/gge — at Hickory CNG Station http://gowal.la/c/NfWN

23 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Trying to find CNG station in the city of Hickory. GPS can't locate the address. It's like a treasure hunt #greentrip

23 May 10 Favorite Reply Delete

castlen Castlen Kennedy

just entered Hickory, NC - time to refuel again! #cng #greentrip

23 May 10 Favorite Reply Delete

castlen Castlen Kennedy

New blog post on wknd adventures http://bit.ly/a4hZDB #cng #greentrip

23 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Getting about 19.5 miles a gallon as we head towards North Carolina. 3greentrip

23 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just passed over into South Carolina #greentrip

23 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Back on the road, stopping in Athens to check out a #cng home fueling device #greentrip

23 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Dinner in Atlanta w @eblakejackson, @chadosko & @cheryldalton — at Brio http://gowal.la/c/N4rQ

22 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Check out the Atlanta bus fleet, over 2/3 run on #cng http://twitpic.com/1q3wxb #greentrip

22 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Scooting around Atlanta in AGL's #CNG Honda civic! #greentrip http://twitpic.com/1q3edf

22 May 10 Favorite Reply Delete

castlen Castlen Kennedy

When I go 65 we get b/w 20-21 mpg, when I go over 70 it drops to b/w 18 & 19 mpg RT @VernonTyger: What's your #CNG mileage? #greentrip

22 May 10 Favorite Reply Delete

castlen Castlen Kennedy

New blog post on the challenges of yesterday http://bit.ly/a4hZDB #cng #greentrip

22 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just lost an hour passing into the Eastern Time Zone. #greentrip

22 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Filled up w #cng in Birmingham for only $1.369 a gallon. Only driving today is to ATL, whew! #greentrip

22 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just arriving in Birmingham ... Only six hours behind schedule :-). #greentrip. Good news though - last leg we got almost 20mpg

22 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Stopped in Prattville, AL and the clerk at the mini-mart did her best impression of the 7 year olds Beyonce's single ladies from YouTube

22 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Did I mention #CNG was $1.39 in Milton? Meanwhile gasoline around the corner was $2.69 #greentrip

21 May 10 Favorite Reply Delete

castlen Castlen Kennedy

WE MADE IT!! http://bit.ly/9UvEEU

21 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just save this to my iPhone favoriteshttp://www.afdc.energy.gov/afdc/locator/m/stations #cng

21 May 10 Favorite Reply Delete

castlen Castlen Kennedy

We made it to Milton after some major delays! It's been an eventful day, chk out the blog www.greenamericanroadtrip.com #cng #greentrip

21 May 10 Favorite Reply Delete

castlen Castlen Kennedy

anyone have contact in Milton FL who has used #cng station there? we have run into an issue on the trip. Please msg me! Thanks #greentrip

21 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just passed the Mississippi state line! #greentrip

21 May 10 Favorite Reply Delete

castlen Castlen Kennedy

weaving through small towns to avoid I-10 traffic, alligator farm detour is in the works! #greentrip

21 May 10 Favorite Reply Delete

castlen Castlen Kennedy@

@chkBarnett what's the most efficient way to drive through very slow heavy traffic? I am trying to conserve my CNG and not waste it idling..

21 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Dead standstill on I-10 East w/ @eblakejackson, @cheryldalton & @chadosko, if we weren't already behind schedule, we are now :) #greentrip

21 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Is there a #CNG station near you? You can check at http://bit.ly/clkiSc #greentrip

21 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Enjoying some Louisiana cuisine at the Tiger Grill — at Tigerbait Grill http://gowal.la/c/MAEh

21 May 10 Favorite Reply Delete

castlen Castlen Kennedy

On my way to learn about incentives for #cng available in Louisiana.

#greentrip

21 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just left a great Lafayette event with @LOGA and @apachecorp. Now driving over Atchafalaya Basin http://twitpic.com/1phohh #greentrip

20 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just arrived in Lafayette, LA! #greentrip

20 May 10 Favorite Reply Delete

castlen Castlen Kennedy

I also have a Flickr page and just uploaded some more pics from yesterday! http://www.flickr.com/photos/greentrip/ #greentrip

20 May 10 Favorite Reply Delete

castlen Castlen Kennedy

finally got my wrap up video from yesterday posted! See how the day went - http://bit.ly/9CFqWV - I'll be more prompt tonight

20 May 10 Favorite Reply Delete

castlen Castlen Kennedy

thank you Cameron LNG , what an amazing tour!

20 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just posted an updated itinerary for the trip. Are we stopping in your town? http://j.mp/946A0b

20 May 10 Favorite Reply Delete

castlen Castlen Kennedy

On our way to check out an LNG import facility in Hackberry, LA! #natgas # greentrip

20 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just entered Louisiana! www.greenamericanroadtrip.com

20 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just topped off at the Beaumont Transit station! They got a federal grant and converted their bus fleet to clean burning #cng! #greentrip

20 May 10 Favorite Reply Delete

castlen Castlen Kennedy

We have a full tank of #cng and are headed east towards Beaumont. Cops everywhere on I-10 E. #greentrip

20 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Day 2 begins with a #cng fill-up at Clean Energy http://twitpic.com/1pdonx #greentrip

20 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Great 1st day! Learned a lot - if you are in Austin, make sure to chk out the TX Gas rebate program http://bit.ly/chsELa #cng #greentrip

19 May 10 Favorite Reply Delete

castlen Castlen Kennedy

#cng cookie anyone? http://twitpic.com/1p9jyb thanks @apachecorp for the end of day snack!

19 May 10 Favorite Reply Delete

castlen Castlen Kennedy

We have had a great #cng filled day but now I need a shot of espresso. http://twitpic.com/1p88hp

19 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just had a great event with @apachecorp. Apache and its partners announced a new Houston #CNG consortium

www.greenamericanroadtrip .com

19 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Just left a great demonstration at Parkway Chevrolet in Tomball. Headed to Apache Corporation in Houston.

19 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Next stop on the Green American Road Trip: Parkway Chevrolet in Tomball! Just arrived and they are going to walk us thru a #cng conversion

19 May 10 Favorite Reply Delete

castlen Castlen Kennedy

Headed East on 290. Blue Bell Ice Cream anyone? #greentrip

19 May 10 Favorite Reply Delete

castlen Castlen Kennedy

And we're off!! Www.greenamericanroadtrip.com #cng #greentrip

19 May 10 Favorite Reply Delete

castlen Castlen Kennedy

On my way to TX Gas Service for some pre trip news interviews! Sendoff event at 8 @LBJSchool #greentrip

19 May 10 Favorite Reply Delete

castlen Castlen Kennedy

T minus 8 hrs till departure! See y'all on the road! Www.greenamericanroadtrip.com #natgas #roadtrip #CNG

19 May 10 Favorite Reply Delete

castlen Castlen Kennedy

On my way to the airport to pick up fellow roadtripper @cheryldalton! #greentrip www.greenamericanroadtrip.com

18 May 10 Favorite Reply Delete

castlen Castlen Kennedy

At KEYE news studios in ATX for interview about my #roadtrip. Leaving tomorrow! #cng #greentrip

18 May 10 Favorite Reply Delete

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